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CARBONISATION TECHNOLOGY AND ENGINEERING.

A PRACTICAL EXPOSITION OF THE PROCESSES EMPLOYED FOR THE CARBONISATION OF COAL AND WOOD BY HIGH AND LOW TEMPERATURE METHODS, WITH AN ACCOUNT OF THE BY-PRODUCTS OBTAINED.

BY

JOHN ARMSTRONG.

With 296 Illustrations, including 19 Folding Diagrams, etc.

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PREFACE.

THE destructive distillation of Coal and Wood, the manufacture of coke and charcoal with recovery of the by-products, viz., Tar, Ammonia, Benzene and its homologues, has become in recent years a subject of the utmost importance. Modern carbonisation practice has progressed so rapidly that the older literature on the subject is somewhat out of date, while information on the various branches connected with it is scattered among various treatises on other matters. A concise and comprehensive view of carbonisation cannot therefore be without interest, especially to those engaged in the coal industry, which is, perhaps, one of the largest and most important in the world.

During the last forty years of my professional life I have had unique opportunities of studying the problems that have arisen in the development of coal carbonisation; and through the experience gained in designing and constructing furnaces and apparatus for various purposes, including those for metallurgy, brick making, glass manufacture and carbonisation, together with many years spent in practical experimental and research work on fuel, I have been enabled to solve successfully some of the problems in connection with the construction of coke ovens and the recovery of by-products.

In the following pages I have endeavoured to place the knowledge thus gained in as concise a manner as possible, treating the subject from the engineering point of view.

The chemistry of carbonisation has been already very well expounded by other authorities; I have, therefore, only touched upon it where it has been necessary.

As the process of carbonisation is dependent greatly upon fireclay goods for the construction of the ovens, furnaces and apparatus connected therewith, I have given a short description of the nature of

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clay and the manufacture of refractories, together with some practical directions for furnace design and construction.

Having very carefully followed the development of the various processes for Low Temperature Carbonisation, I have given a short *résumé* of some of the most important. I have also made a few remarks upon the economical combustion of fuel and the abolition of smoke, which will be found in the concluding pages of this work.

Permission has been obtained from His Majesty's Stationery Office for making the extracts quoted in this work from Government publications. My thanks are also due to the firms who have so kindly assisted me with reports and descriptions of the latest developments in coal washing, coking, and by-product plant, among whom are the following, viz. :—Messrs. Coppée & Co., Coke Oven Company, London ; Messrs. Bryan Donkin & Co., London and Chesterfield ; Messrs. Holmes & Co., Huddersfield ; Messrs. Foote Mineral Co., U.S.A. ; The Glenboig Fireclay Co., Glasgow ; Messrs. Head, Wrightson & Co., London ; Messrs. Hardy Patent Pick Co., Sheffield ; Messrs. Koppers Coke Oven Co., Ltd., Sheffield ; Messrs. Otto Coke Oven Co., London ; Messrs. Semet-Solvay Coke Oven Co., Sheffield ; Messrs. Simon-Carves & Co., Manchester ; Messrs. The Low Temperature Carbonisation Co., Ltd., London ; Messrs. Reavell & Co., Ipswich ; Mr. Lamplough, London ; Mr. Marshall, London ; and Messrs. W. P. Thompson & Co., Patent Agents, 12 Church Street, Liverpool, and 50 Lincoln's Inn Fields, London, W.C.

I desire also to thank my publishers for their great assistance during the preparation and production of this book.

JOHN ARMSTRONG.

London, *December*, 1928.

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CARBONISATION TECHNOLOGY.

INTRODUCTION.

Organic materials, such as Coal, Wood, Peat, Lignite, etc., in order to concentrate the carbon contents and separate them from the other constituents, are submitted to the process termed *Carbonisation*, which separates the carbon and the inorganic matter on the one hand, from the gaseous matter and the condensates obtained therefrom on the other hand.

This process consists simply in heating the substance under certain conditions for the purpose of obtaining this separation ; nothing whatever is required to be added for carrying out the process. The reaction takes place often at a very low temperature ; but to obtain certain desired results the process must be conducted out of contact with air and in suitable apparatus.

Unlike, therefore, most chemical and metallurgical reactions, which require reagents to be added before separation can be accomplished, heat only is required in the process of carbonisation.

This process would seem, at the first glance, to be extremely simple, but to obtain the separation of carbon from its matrix, as found in nature, requires in some cases very complicated apparatus, and that it should pass through a process by no means simple, requiring the utmost care and perseverance for the achievement of the desired results, which in the past have only been gained after long and tedious experimental work.

The separation of carbon from the gaseous ingredients irrespective of the form of the residual matter can be conducted by very simple methods, such as carbonising wood or coal in heaps, allowing all the volatile matter to escape; the residual carbon with the inorganic matter originally contained therein will be recovered minus the carbon which is volatilised in the process. This was the original practice in the early attempts at carbonisation, but when it was subsequently observed that there was great value in the volatilised constituents, attempts were made to secure these, and by so doing the foundations were laid of the modern practice of carbonisation with recovery of by-products.

At first the results were poor, but by improvements in the apparatus used and in the processes employed results were obtained that led to further development, until the present practice was established, in which in some instances the by-products have become more valuable than the carbon residue in the form of coke.

The perfection of the methods and apparatus for obtaining the various substances separated in the carbonisation of coal is most wonderful, and has opened up a completely new field of operations forming an enormous branch of chemical science, by which substances are produced that have become of the

utmost necessity, value, and importance in a great number of the arts and manufactures.

It would be erroneous, however, to imagine that the final stage has been reached in the development of this branch of science, and that the most economical result has been obtained; this cannot be conceived as long as raw coal is consumed, producing smoke, either in the steam boiler or the domestic fire, in both of which there is an enormous waste going on, not only of the heat produced, but of valuable constituents by their escape up the chimney.

Scientific investigation is still being pursued in this direction, and a great number of chemists and engineers are daily experimenting and bringing forward their achievements with a view to eliminating the production of smoke, and obtaining economically all the value in the coal.

It is not only in the process of carbonisation that some of these later achievements have been successfully attained, but in some of the preliminary operations in preparing the coal for carbonisation. In the mining operations that are now carried out greater economy is exercised than obtained some years ago. It was the practice to leave part of the coal, such as small coal, in the mine, as not being of any use, there being quite enough then of the large good coal; this is being altered, and all the available coal is now brought to the bank and put through certain preliminary processes of sizing, screening, washing, jigging, etc., and even that which was adhering to pieces of rock, is now crushed and the rock separated by means of these processes, and the coal recovered; this principle has been pursued so far as to recover by means of flotation processes all the fine coal dust that was formerly carried away by the wash-water; it is separated by this process from the gangue, and in the coking coal area good coke can be made from it, or it can be briquetted and the gas and by-products obtained, or completely gasified if required.

The handling of coal, and its storage have also had considerable attention from colliery engineers, and labour saving apparatus has been installed by which greater daily output can be obtained at less cost than formerly.

Propositions have been made to save cost and loss in the transportation of coal from the mine to the consumer, by converting the coal at the pit mouth into smokeless fuel and gaseous constituents, or to develop electrical power, but there are difficulties and losses to be contended with in all such propositions hitherto advanced in relation to this problem; whether these can be overcome or not cannot at present be definitely ascertained, but great improvement may be made upon the system now in operation for the transport and consumption of raw coal.

It was very early discovered that by heating coal a combustible gas was given off, which emitted light superior to that obtained from candles, and in order to obtain this gas, apparatus was devised, consisting of closed vessels or retorts which were externally heated, the gas being conducted away by means of pipes. The atmospheric air being thus excluded, the carbon residue was secured at the end of the operation in the form of coke. Iron retorts of course were first tried by these pioneers of carbonisation to carry out their operations, but a demand having arisen for products in larger quantities, endeavours were made to increase the output by higher temperatures; this was achieved with success, but at the expense of the retorts, which did not stand the elevated temperature and required frequent repairs and renewals. Iron retorts were good conductors of heat, in fact better than clay retorts, and several forms were tried but without economic success, consequently metal retorts were ultimately abandoned in favour of clay retorts.

On the introduction of retorts made of fireclay, difficulties at once presented themselves. The clay retorts stood well the temperature required—that is, they did not sag or melt down as in the case of iron retorts, but being made in one piece they cracked, necessitating new ones ; but they all followed the same course, until it was discovered by prolonged heating, and charging the cracked retort several times, that the leakage of gas through the cracks diminished, and ultimately ceased, due to the condensation of the carbon from the gas in its passage through the cracks, the deposit entirely blocking them, and this not only stopped the leakage of the gas but practically cemented up the cracks with hard carbon, forming a complete gas-tight retort that could be heated to temperatures beyond the melting point of cast iron without destruction and by means of which the production of a larger quantity of gas and superior coke was possible.

Improvements were then made in the means of heating these retorts in the settings, with a view to economical firing and efficient heating.

Firing by hand upon grates under the retorts was discarded, and gas firing adopted so that by this means cleaner and more efficient firing, and higher temperatures could be secured, with a more regular output of gas, and with less wear and tear upon the furnaces. Cold coke was used at the outset to replenish the gas producers, but an important improvement was also adopted in securing the initial heat of the coke drawn from the retort direct into the producer, and while thus securing the initial heat of the coke, preventing the chilling effect and reduction of temperature occasioned by the introduction of cold coke into the gas producer. Yet another improvement consisted in pre-heating the air for the combustion of the gas in the settings, by means of recuperators, extracting the heat from the spent gases of combustion in their exit to the chimney, thus securing another item of economy in conducting back the heat that would otherwise have been lost to the combustion chamber, at the same time saving the heat units that would be required in heating the incoming air up to the combustion point, and obtaining a more regular and higher temperature, two of the most important considerations in the process of the carbonisation of coal.

While these developments and improvements were being made in the manufacture of gas, great strides were being made in the process of manufacturing Foundry and Furnace Coke, and the recovery of gas-tar, ammonia, and benzols, both at the gas-works and the coke ovens.

With regard to the manufacture of foundry and furnace coke—that is, coke made with the primary object of concentrating the carbon into a hard compact mass for metallurgical purposes, this required quite a different treatment in the process of carbonisation from that practised in the manufacture of lighting gas, where the primary object is the production of the largest quantity of gas irrespective of the quality of the residual coke produced.

When, therefore, hard coke was to be produced, in the earliest attempts the process was conducted in heaps, but as the industry developed and the gas, tar and other products were collected and utilised, ovens were used along with extensive and complicated plant and machinery for recovery of these by-products.

For a long time the best metallurgical coke was made in the round or square oven, called the Bee-hive oven, in which the coal was carbonised by the heat produced by the combustion of the gas distilled from the coal, ignited and burned above the charge of coal inside the oven, the carbonisation proceeding downwards very slowly, the total volatile matter together with a portion of the coal on the surface of the charge being consumed. This process produced

excellent coke for metallurgical purposes but was wasteful; it is for a certain class of coal still used; but when the gas, tar, ammonia and benzol were found to be valuable and their recovery became remunerative other forms of ovens were designed for the purpose of collecting these substances and at the same time expediting the process.

The experience gained by the carbonisation of coal in the round or Beehive oven suggested at the outset the heating of the oven bottoms, and all ovens of the early type are provided with a fireplace under the sole of the oven.

As in the manufacture of gas using iron retorts there were difficulties encountered which were overcome by using clay retorts, so in the manufacture of coke, difficulties occurred of a more serious character, which took years of experimental and practical working to understand and master; one of the chief of these difficulties lay in the application of heat to the walls of the ovens, and in order to accomplish this, several types of ovens were designed with more or less success; some had vertical and some horizontal heating flues; the latter were more easily managed, on account of their length, which allowed the development of the flame and the complete combustion of the gas previous to its exit to the chimney; the vertical flues being short, the process of complete combustion had to take place in their height, or to finish the combustion at the top, the temperature would there have to be highest, where it was least required, if the gas produced was to be treated subsequently for the recovery of by-products.

These facts gave rise to numerous groupings of vertical flues. With direct, continuous heating, or in the regenerative type, reversible heating was employed; both of these types have now been brought to something like practical perfection as regards heating with regularity, and results have been produced that have given every satisfaction.

In the successful direct vertical flue heating, which gave least trouble, the Bunsen burner principle was used, with a gas jet to each separate flue, so that by this means the regulation of temperature could be under control, with a separate gas and air valve to each individual flue, while on the other hand the heating of a group of flues from one common gas pipe, or air inlet, gave rise to short circuits, and bad heats. This difficulty was overcome by means of the system of regeneration, introduced by Siemens, which consisted of heating the incoming air by passing the outgoing products of combustion through chambers containing chequer brickwork, in which the heat was extracted from the hot gases, and delivered up again to the cold air as it was made to traverse the chambers previous to its introduction to the gas in the combustion flues. By thus pre-heating the air for combustion, higher temperatures could be maintained, and the flues, hitherto difficult to heat uniformly, could be heated to an even temperature, by the operation or reversing the direction of the heating gases, using one group of flues for the first period of heating (usually half an hour) as the heating flues and the other group as exit flues. For the second period, when the heating gases were reversed, the first group became the exit flues for the gases to the chimney, while the other group became the heating flues.

The economic heating of narrow flues in the walls of coke ovens, with equability of temperature, to the highest point necessary for the complete and rapid carbonisation of certain coals is no easy task, as the high temperature is difficult to produce uniformly all through the several flues without local super-heating, and the consequent partial fluxing of the refractory material composing the structure of the walls of the ovens. This difficulty has presented

itself to all coke oven builders at one time or another, and is to be surmounted only by careful manipulation and the attention of the attendant while the process of carbonisation is taking place. With moderate temperature working, the overheating problem does not generally appear, and there is therefore less risk of damage being done; nevertheless there are certain coals that will only produce coke of a suitable quality by high temperature and pressure during the period of carbonisation, and with the above facts in view, a quite different type of oven was designed to meet these requirements. The horizontal type of coke oven not being suitable, a vertical oven was designed, in single units, which proved satisfactory in producing good coke from this class of coal, generally very high in volatile matter, such as the Lanarkshire coal.

It is therefore necessary before constructing a coking plant to ascertain the coking power of the coal proposed to be carbonised, and the type of oven required to give the best results. It is also no less necessary to ascertain before laying down a plant for the recovery of ammonia that the nitrogen contained in the coal will be ultimately recovered as ammonia, as in certain coals this is not so, the nitrogen passing off as nitrogen with the other gases, and cannot be recovered as ammonia.

The carbonisation of coal or other carbonaceous substance by the process of heating is necessarily a comparatively slow one, by reason of the bad conductivity of heat by the coal or coke produced; this fact has been one of the problems for solution in all departments of the process and never so difficult as when the proposition is to conduct the process of carbonisation at a low temperature—that is, at a temperature below 600° Cent. One of the chief obstacles that presents itself in low temperature carbonisation is incomplete conversion into coke, which does not result in the contraction necessary to release the coked coal from the walls of the retort or apparatus in which the process is conducted, after the period of carbonisation is finished.

This insufficient contraction and the slow progress of the heat through the mass under treatment, makes the egress of the gases difficult, and often impossible, thus giving rise to irregularities and dangerous stoppages. This difficulty has lately been overcome by the employment of special plant and by other means, such as employing a short period of high temperature to effect local separation of the coke from the walls of the retort.

The penetration of heat into a mass of coal undergoing carbonisation decreases with the distance which obtains, and so much so as to produce highly carbonised coke in the region of the application of the heat, while uncoked and comparatively cold coal will be found in the centre or in that region furthest away from the source of heat. Advantage is taken of this fact in the filtering of the gases given off in the process conducted in vertical ovens of wide capacity, where the gases are forced to make their exit through the uncoked coal, thereby becoming divested of the tarry matter so difficult otherwise to condense, and by this means increasing the amount and quality of the coke subsequently formed from this deposit of tar, as the tarry matters carry away with them comparatively little ash, the binding medium of the tarry matter forming coke of a superior purity and hardness.

The same process of compelling the gases to pass through the uncoked coal in their exit is present in the carbonisation of coal in the round or Bee-hive oven; the coked crust of coal on the top, with the liquid stratum of melted coal immediately underneath, preventing any passage to the gaseous products given off during the process; these have to find their way through the uncoked coal to the nearest crack or fissure in the superincumbent mass of coke.

The coking process for the production of first class metallurgical coke is dependent upon certain qualities in the coal employed, there being very few if any forms of oven or apparatus capable of dealing with all and every class of coal, with like success. Modifications have therefore to be made in the process and apparatus to suit the requirements of the different coals. The coking principle in a coal is not well understood, but it seems to be connected with certain qualities of the tarry bodies in the coal; coals high in oxygen and hydrogen, or low in these gases, do not coke, coking power seeming to lie between these extremes.

But even with coals of the same apparent analyses, the one may form excellent coke, while the other will not; and the weathering of coal—that is, the absorption of oxygen by the coal prior to its carbonisation—will interfere very greatly with the coking power; in fact it is sufficient to powder a good coking coal and expose it to the atmosphere for a few days, to find that its coking power has diminished, and by prolonged exposure it will ultimately become absolutely uncokable. When a coal has once lost this coking power it cannot be subsequently restored.

It was at one time thought that the saving of the by-product was at the expense of producing good coke, but this has been proved to be erroneous, and first-class coke for all purposes has been made in modern ovens and apparatus in which the tar, ammonia and benzols have been successfully recovered.

The recovery of the by-products in this country—*i.e.*, Great Britain—is of very recent date; previous to 1914 tar was a drug on the market and benzol did not pay for recovery. The industry carried on in this country of the carbonisation of coal was dependent upon the gas companies for the supply of gas, and the coke maker for the production of metallurgical coke for the iron smelter. The dye industry having passed to Germany, the by-products that were produced here were exported to Germany for this industry and for the manufacture of high explosives.

It was when the great war awakened the producers of coke and gas to the fact that high explosives were required and their ingredients were made from the by-products of coal carbonisation that the industry really became a producer here of benzol on a large scale; sulphate of ammonia was produced prior to the war, it being recognised as a good fertiliser, and considerable quantities were exported, but the quantity now produced could be very easily augmented if attention was paid to its recovery, prior to the consumption of the coal in its raw state.

The development of the internal combustion engine, demanding large supplies of benzol, has added a stimulus for its recovery from the gases of coke ovens and gas works, and large plants have been laid down and successfully worked for this purpose, and in some instances another branch has been further developed at the gas and coke works in the manufacture of colours and other chemicals, together with the recovery of sulphur as sulphuric acid from coke oven gases used in the process carried on for the recovery of ammonia as sulphate of ammonia.

The development of tar distillation has provided another source for the recovery of additional supplies of benzol and other chemical products, with residual pitch; the latter material is in use to a large extent for the purpose of forming a binder in the manufacture of briquette fuel from coal that would by reason of its comminution be unfit to burn in the ordinary way. The only drawback to the use of this binder is the amount of smoke produced owing to the difficulty of its combustion, and this is to a certain extent exaggerated by

the comparative solidity of the briquette, produced by the pressure employed in its manufacture, and by reason of the agglutination of the particles of coal by the pitch. This solidity prevents the access of air to the briquette under combustion, and thus produces smoke. Making these briquettes with perforations for this purpose has been tried, but with little success, as it is not so much perforation made by mechanical means that is required, as aeration or sponginess, so that the coal or the substance of the briquette will be, every particle of it, subject to the access of air during its combustion.

It is this solidity in coal itself that tends to produce smoke to a large extent, when thrown upon a hot fire, and the same may be said in the case of pitch, when burned by itself; these substances are too solid for complete combustion, they prevent the due amount of oxygen entering into the chemical reaction to produce carbonic acid gas, the ultimate result of complete combustion of these substances.

The processes carried on in the carbonisation of organic substances, such as wood, peat, coal or animal remains, could not be so well or economically conducted without the aid of refractory materials in the construction of the retorts and furnaces required for this purpose.

Great developments have been made in this branch of the industry, not only in the more perfect manner in which the retorts are made, but in their composition, by the judicious mixture of the ingredients required to produce bricks or retorts to withstand high temperatures.*

Native clays used to be depended upon solely in the early days to meet all requirements, and failure in many instances was the direct result of imperfect materials employed; certain clays were found to possess in a large degree the constituents required to form good bricks or retorts, but these clays were limited in quantity and confined to certain localities; such were the best clays of the Stourbridge deposits. But ultimately, to supply an ever increasing demand for highly refractory materials, mixtures of the required chemical composition in the several ingredients were arranged, so that a clay was produced with all the advantages of the one required, but which could not be obtained otherwise. Bricks and retorts made from a local clay, good in every respect but deficient in silica, alumina, or other necessary ingredient, are now obtained by admixture of clays containing those substances necessary for the production of the required refractory material.

It is no less necessary after the brick or retort has been formed with the best refractory material, to have it well burned without distortion, and care has to be exercised in the desiccation as well as the subsequent firing to provide satisfactory results.

Firebricks require to be thoroughly desiccated and burned until the limit of contraction has been attained, generally by the application in the burning of a temperature equal to that to which the goods will be subsequently exposed when built into their respective places in the furnace.

Discrimination in the choice of refractories, such as bricks composed of different refractory materials, is now practised with great success in the construction of furnaces and settings in which high temperatures are necessary, placing the highest refractory where it is exposed to the highest temperature; but this can only be successfully accomplished in gas firing; for example silica bricks in the flues of a gas-fired furnace will stand very high temperatures, much higher in fact than a neutral fire-brick; but when placed in a coal or coke fired furnace grate, they will not stand at all; the ash in the coal or coke

* See "Refractory Materials," by A. B. Searle. London: C. Griffin & Co., Ltd.

forms very easily fusible silicates with the silica brick and fluxes it away in a short time.

The problem is anything but solved regarding the manufacture of the highest refractories; the chief difficulty is in the binding or agglomeration of the particles into a coherent mass to form a brick or retort that will not subsequently fall to pieces when exposed to practical use in the furnace.

The chief features that are required in refractory materials used in the processes of carbonisation are:—Standing up to high temperatures without distortion; without shrinkage or swelling, and without softening or cracking; these are qualities possessed by comparatively few individual refractories which will also stand the necessarily periodic cooling effect of a cold damp charge of coal immediately following the discharge of hot coke from a coke oven working at a high temperature, especially in the winter when the coal arrives from the washeries in a soaking wet, or half frozen state, thus producing a sharp reduction of temperature on the inner surface of the oven walls, while the surface on the other side exposed to the flame in the flues may be at a white heat.

It will therefore be evident that a great strain is thus imposed on the refractory materials composing the walls of the coke oven, and not every refractory is capable of standing up for any length of time to these conditions.

Vast improvements have, however, been made in this department in recent times, whereby the desirable clay mixture is secured to produce the refractory material to serve this purpose economically.

CHAPTER I.

CONSTITUTION OF COAL—GEOLOGICAL FORMATION.

What is Coal?—This question was the subject of a remarkable law-suit in the High Court at Edinburgh, in 1853, before a special jury. The owners of an estate at Torbanhill in Linlithgowshire, granted a lease to mine "The whole coal, ironstone, limestone, and fireclay contained within it, except copper, and any other minerals whatsoever than those specified." In the mining operations a mineral was brought to the surface and was sold for making illuminating gas, from which a very large profit was obtained. The lessors denied that this mineral in question was coal, and thereupon sought an injunction to stop the lessees from working it. The trial brought out some curious facts, and most diverse opinions from the scientific witnesses called to give evidence in the case. These witnesses were practical gas engineers, chemists, geologists, microscopists, coal-viewers, mining engineers, botanists, etc. Some of these witnesses maintained that it was coal, and nothing but coal, while others were of the opinion that it was a bituminous schist. The Judge, with such conflicting scientific evidence before him, simply ignored it altogether, and summed up the case as follows, "The question for you (addressing the Jury) to consider is not one of motives, but what is this mineral? Was it coal in the language of those persons who deal and treat with that matter, and in ordinary language of Scotland? **because to find a scientific definition of coal after what has been brought to light within the last five days is out of the question.** But was it coal in the common use of that word, as it must be understood to be used in language that does not profess to be the purest science, but in the ordinary acceptation of business transactions, reduced to writing? Was it coal in that sense? That is the question for you to solve, for you to determine." The Jury found that it was coal, and very probably of a very good quality, much better than some of the mineral at present on the market sold as coal, containing large amounts of top and bottom rock, or large amounts of incombustible inorganic material from which the ash content is derived. It may be, and probably is, a fact, that where such coal is found in the market it brings a much lower price, but to be just, coal ought to be sold on its organic contents, that is, on the number of units of heat it will produce from its carbon or hydrocarbon contents, just as gas is now being sold on its thermal value by the gas companies.

It must not be supposed, however, that coal is the only mineral that will burn, there are bituminous schists, as some of the witnesses declared at the trial, that will burn like coal. There are the shales from which oil is obtained, very near to Torbanhill, and there are silica and lime deposits saturated with hydrocarbon that will also take fire and burn, but there is a very wide difference between these and true coal.

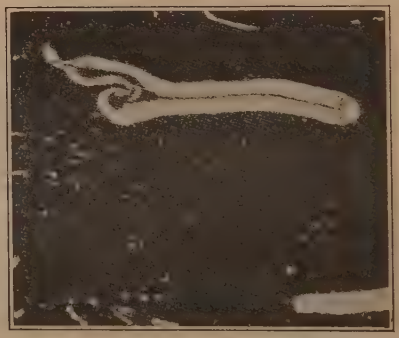
Coal is a mineral of which the contents are composed of carbon and hydrocarbons. When heated out of contact with air it will give off these hydro-

carbons with a residue of carbon left behind in the form of coke with the coking class of coals, and in the anthracite class of coal the carbon contents will be completely combustible. Some qualities of anthracite have as high as 96 to 98 per cent. carbon.

From What is Coal Derived?—Is it a natural mineral deposit, such as iron, lead or zinc? Or is it a mineral of the same family as graphite or the diamond, both of which are carbon?

The question is a difficult one to answer positively, to do so one would require to know the source or origin of both the diamond and graphite. It is generally believed, however, that the coal measures are of organic origin, microscopic investigations show, in a large number of specimens the cuticle, or bark and what is termed spores of the plants from which the coal has been formed (see fig. 1, *a* and *b*); on the other hand there is a very large amount of coal in which this is not the case; are we then to assume that all coal is of vegetable origin? Are we to go a step further and assume that all carbon is of vegetable origin? To do so would be

(*a*) Section of Macrospores, from English Bituminous Coal (Stopes and Wheeler).



(*b*) Section of a collapsed Macrospore, English Bituminous Coal (Stopes and Wheeler).

Fig. 1.

going a little too far, as there is evidence of carbon existing before the coal measures were laid down, and it is doubtless one of the elements, from which the world has been formed. Was all the original carbon in the elementary world consumed and converted to carbonic acid? Was there any left on the yet half-formed Earth and deposited in the coal measures, or was it chemically possible for carbon to be deposited from the atmosphere, which was evidently charged with carbon during what is termed the Carboniferous period? We can only judge of the atmosphere as we now have it, in its constant proportions of oxygen and nitrogen, and cannot conceive what the atmosphere was like before or during the period when the coal measures were laid down. There is no doubt that there was much less oxygen uncombined; the oxygen was no doubt set free by the reaction of calcium, in the formation of the carboniferous limestone rocks. This reaction probably took place in the upper atmosphere, the calcium carbonate falling on the earth in showers at sundry periods; the evidence of these rocks and the superimposed strata being formed by such accretions periodically lies in the fact that, below these deposits are the igneous

rocks; from whence, therefore, are the carboniferous deposits, and over these the superimposed strata of silica and other minerals?

Geologists tell us these were laid down in water (sea deposits); this is no doubt true in part, but in such a theory there are difficulties to contend with which makes the water deposition hypothesis very hard to understand, from the fact that water is very mobile, and very quickly finds its own level by gravitation, and to make the water deposition the sole source of the carboniferous strata, it is required to submerge the land, then raise it, then submerge it, and raise it for every deposit of coal and its super deposit of either limestone, gravel, clay, etc.

Apart from the theory set forth above, of the deposition of carbon in certain areas of the coal measures from the atmosphere, and assuming the origin of coal from the organic life of the vegetable world, growing on its still warm surface, some other explanation is necessary, more reasonable than the rising of the land to grow its vegetable carbon, then sinking beneath the sea to receive its deposits of sedimentary super strata.

It is with this problem in view that the theory of accretion is put forward here, as a more reasonable explanation of the several superimposed seams of coal found in mining operations. It is a well-known astronomical fact that the earth at certain seasons passes through what are called the Leonids—that is, a stream of meteorites situated in the region of Leo. These meteorites appear as shooting stars, when they strike this atmosphere; their velocity is so great that they develop a great heat by reason of the contact they make with the atmosphere. A fine display of them was recorded in the year 1866 in the Eastern hemisphere, and in the Western hemisphere in 1867. These celestial bodies perform an orbit round the sun; the earth crosses their orbit every year, but as their orbit is a large one, and their stream does not make a continuous chain, the earth only strikes the asteroids stream once in 33 years, but it is probable that this stream was much greater than it is at present, and even very much more dense, so that by the passing of the earth through it showers of stones, gravel, sand, etc., would be thrown on the earth, the larger asteroids exploding as they came into contact with the atmosphere, giving the to great clouds of fire dust, which, falling upon the vegetation then existing on the surface of the earth, would envelop it and bury it, another vegetation taking place on its surface subsequently. It would be impossible for solid matter to fall on the earth in this manner if the velocity of the stream was anything like that at which it is calculated at present, viz., 30 miles per second; as the earth's velocity is ascertained to be about 18 miles per second, coming therefore in direct collision, the meteorites would be reduced almost instantaneously to a gaseous state. If, however, we consider the atmosphere charged at this period with CO_2, the combustion would not so readily take place, the falling masses would be heated to the molten state, and fall in a soft, globular form. A large amount of the stones that are found in gravel points to this having happened; some are flattened by their compact with the earth, while if a section is cut through one of these stones, it shows that it has been formed as a globe, with different coloured concentric rings round the inner core.

Some will assert that all gravel stones are formed by the action of water, as in rivers and on the sea shore; this action would certainly give the outer form to the pebbles, but could not possibly account for the concentric rings inside.

It is, therefore, very probable that the earth has in ages past caught up these

meteorites, which are stated to be innumerable myriads; the diagram shows the path of their orbit and the orbit of the earth round the sun, which traverses the former every year at A (fig. 2), but misses, at present, the main body of them as at B, until B advances once in 33 years to the position of A, when the earth runs through them and takes up a portion. There is little doubt that this stream is getting smaller, and in course of time will be extinct, as it is gathered up by the earth or into the sun. It is from this reasoning that we think this stream was at one time very dense, and that the earth has benefitted by these accretions, buried so that the superincumbent weight of the overlaying masses has provided the necessary heat and pressure to convert the vegetable matter into Coal.

It is recorded that besides meteorites of silica and iron, and other materials, carbon has actually been found on the earth from Celestial sources, viz.:—

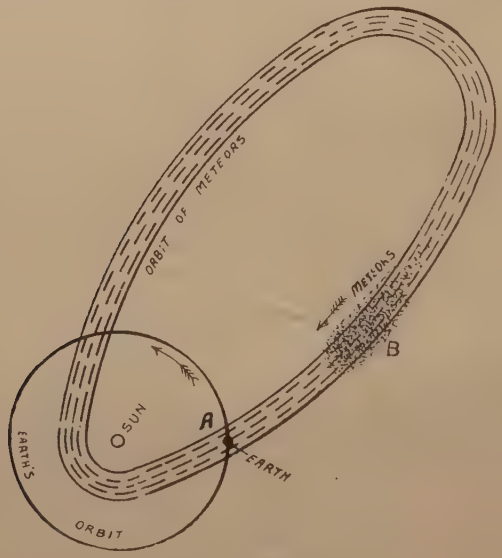


Fig. 2.—Meteorites.

"For an aërolite of a different type, we may refer to the carbonaceous meteorite of Orgeuil, which fell in France on the 14th May, 1864. On the occasion of its descent, a splendid meteor was seen, rivalling the moon in size. The actual diameter of this globe of fire must have been some hundreds of yards. There were actually found nearly a hundred fragments of the body scattered about over a tract of country fifteen miles long. This object is of particular interest, inasmuch as it belongs to a rare group of aërolites, from which metallic iron is absent. It contains many of the same minerals which are met with in other meteorites, but they are **associated with Carbon,** and with substances of a white or yellowish crystallisable material, soluble in ether, and resembling some of the hydrocarbons. Such a substance, if found on the earth, would probably be deemed a product resulting from animal or vegetable life." *

It will thus be evident from this, that it is possible to suppose that carbon was deposited on the earth, and this is now found as coal, or diamond or graphite.

* "The Story of the Heavens," Sir Robert Ball, LL.D., p. 257.

On the other hand, there is, as previously stated, strong evidence of the organic origin of coal, in certain strata, but the theory put forward of its formation, as already referred to, by the subsidence of the land, and subsequent elevation, cannot be reasonably understood as universal. There is no doubt that there was such submersion; and an accumulation of marine deposits of mud, sea-shells, sand, etc., were piled upon it, but surely this aqueous deposition could not account for the enormous amount of the substrata, thousands of feet in thickness, without a large amount of accretion from celestial space; and at a time when the atmosphere was highly charged with carbon. The organic vegetable matter in the form of ferns, mosses, tall and luxuriant conifers, has been discovered in the coal measures, and it is very reasonable to suppose that under such circumstances of heat, carbonic acid, and water vapour, this vegetation was of rapid growth. There was sunlight, but it is also probable that the amount of vapour in the atmosphere shut out the direct rays of the sun, while the density of the atmosphere rendered its heat greater than at present, and warm even at the poles.

As we ascend into the more rarified regions of the atmosphere, the sun's rays do not give the same heat as in the deep valleys, even in equatorial regions; it is therefore assumable, that if the atmosphere was charged with CO_2, which is a very heavy, dense gas, the rays of the sun in penetrating a mass probably extending much higher than our present atmosphere, would have a higher temperature over a very much larger surface of the earth, and combined with the initial heat of the earth itself, which would be retained by reason of the density of the atmosphere, forming a semi-tropical region right up to, and within, the Arctic Circle, thus accounting for the presence of large coal deposits near the North Pole, in Spitzbergen, which must have been laid down, if from vegetation, in a much warmer atmosphere than there is there at present.

There are other considerations which point to the fact that sudden catastrophies of accretion happened. "Evidence of the fact of vast numbers of fishes and saurians having met with sudden death and immediate burial is also afforded by the state of entire preservation in which the bodies of hundreds of them are often found in the Lias. It sometimes happens that scarcely a single bone, or scale, has been removed from the place it occupied during life; this condition could not possibly have been retained had the uncovered bodies of these animals been left, even for a few hours, exposed to putrefaction, and to the attacks of fishes and other smaller animals at the bottom of the sea.

Another celebrated deposit of fossil fishes is that of the cupriferous slate surrounding the Hartz. Many of the fishes of this slate at Mansfeld, Eiseleben, etc., have a distorted attitude, which has often been assigned to writhing in the agonies of death. The true origin of this condition is the unequal contraction of the muscular fibres, which causes fish and other animals to become stiff during a short interval between death and the flaccid state preceding decomposition.

As these fossil fishes maintain the attitude of the rigid state immediately succeeding death, it follows that they were buried before putrefaction had commenced." *

Again Buckland states: "Cuvier drew his figures of the recent sepia with ink extracted from its own body. I have drawings of the remains of extinct species prepared with their own ink; with this fossil ink I might record the fact, and explain the cause, of its wonderful preservation. I might register the proofs of instantaneous death detected in these ink-bags, for they contain

* Buckland, *Bridgewater Treatise*, "Geology and Mineralogy," 1836, vol. i., p. 125.

the fluid which the living sepia emits in the moment of alarm; and might detail further evidence of their immediate burial, in the retention of the forms of those distended members. Fig. 3 shows these intact, since they would speedily have decayed, and have spilt the ink, had they been exposed but for a few hours to decomposition in the water. The animals must therefore have died *suddenly*, and been *quickly* buried in the sediment that formed the strata, in

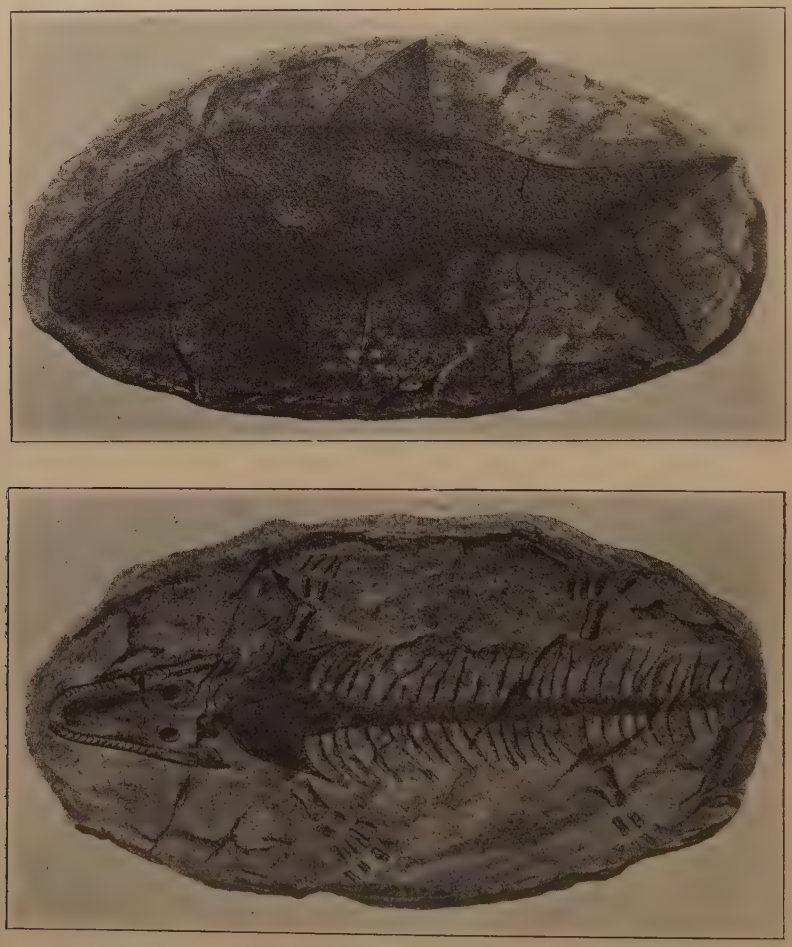


Fig. 3.—Fossilised Fishes in Coal, from the Coal Measures of Sarrebrück ("La Vie Souterraine").

which their petrified ink and ink bags are thus preserved. The preservation also of so fragile a substance as the pen of the Loligo, retaining traces even of its minutest fibres of growth, is not much less remarkable than the fossil condition of the ink-bags, and leads to similar conclusions. We learn from a recent German publication (*Zeiten's Versteinerungen Württembergs*, Stuttgart, 1832, PL. 25 and PL. 37) that similar remains of pens and ink bags are of frequent occurrence in the Lias shale of Aalen and Boll. Hence it is clear that the same

causes which produced these effects during the deposition of the Lias of Lyme Regis, produced similar and nearly contemporaneous effects in that part of Germany which presents such identity in the character and circumstances of these delicate organic remains." *

These facts from the Lias of Lyme Regis, and from Germany, point to the entombment of a very wide area, practically at the same time, and of the same sudden nature, completely burying and effectually sealing these organic remains from putrefaction or influence of the atmosphere. It is, therefore, probable that the sudden deposition by accretion from space of the overlaying strata was the cause of thus burying and preserving these fossil remains.

When the coal was laid down, we have unmistakable evidence of a sudden catastrophe, where fishes, flora, and fauna, and even insects, have been caught, imprisoned and petrified; these are found intact, as in life, and point to some sudden entombment, otherwise they would have been decomposed. The entombment was not only immediate but complete, shutting out the atmosphere, thus preserving them, until they became in time completely petrified. This entombment also points to an accretion of dry material to a great thickness, otherwise the oxygen of any water would have quickly decomposed these organic remains, so that it could not have been in these instances one of submersion, which would be slow in operation and fatal to the organic forms thus embedded.

The flora of the coal measures may have been huge peat bogs, with conifers and ferns growing in them from which, year after year, the leaves and branches falling around, would accumulate fast, the portions lying at the bottom would decompose and form humus, not coal, the humus afterwards turning into vegetable soil. This was what would happen to provide a ground where vegetation would grow; but this vegetation, to form coal, must not decompose, it must be buried before decomposition sets in. Evidently the growth was extremely rapid, and buried the undergrowth, until the cataclysmical accretion arrived, and piled up the inorganic material upon it, sealing it up from the action of the atmosphere, at the same time adding great pressure.

"Long continued growth and decay of vegetation upon a land surface not only promotes disintegration of the superficial rock, but produces an organic residue, the intermingling of which with mineral dé bris constitutes vegetable soil. Undisturbed through long ages, this process has, under favourable conditions, given rise to thick accumulations of a rich dark loam. Such are the "regur," or rich black cotton soil of India, the "tehernayzem," or black earth of Russia, containing from 6 to 10 per cent. of organic matter, and the deep fertile soil of the American prairies and savannahs. These formations cover plains many thousands of square miles in extent." †

This is proved by the coal measures where the vegetable soil is found *in situ*, and where the Sigillaria (fig. 4), which probably formed the greater part of this coal measure, has its roots embedded in the fireclay, which was the original natural soil on which it grew, but from which all the alkali has been extracted by the plant; this fireclay was originally formed from the humus of the decomposition of former Sigillaria or other vegetation.

The plant which supplied the older coal measures with coal is undoubtedly of this family. No specimens are now extant in the vegetable world; it seems to have been extinct for many ages, probably on account of changes in environment, absence of carbon in the atmosphere, and other changes;

* Buckland, *Bridgewater Treatise*, vol. i., p. 308.
† Geikie, "Text-Book of Geology," p. 442.

but other forms of vegetation, such as peat, moss, and ferns may be the factors in supplying the coal of the more recent formations, and the lignites. Sigillaria, therefore, played its part in clearing the atmosphere of carbon, and

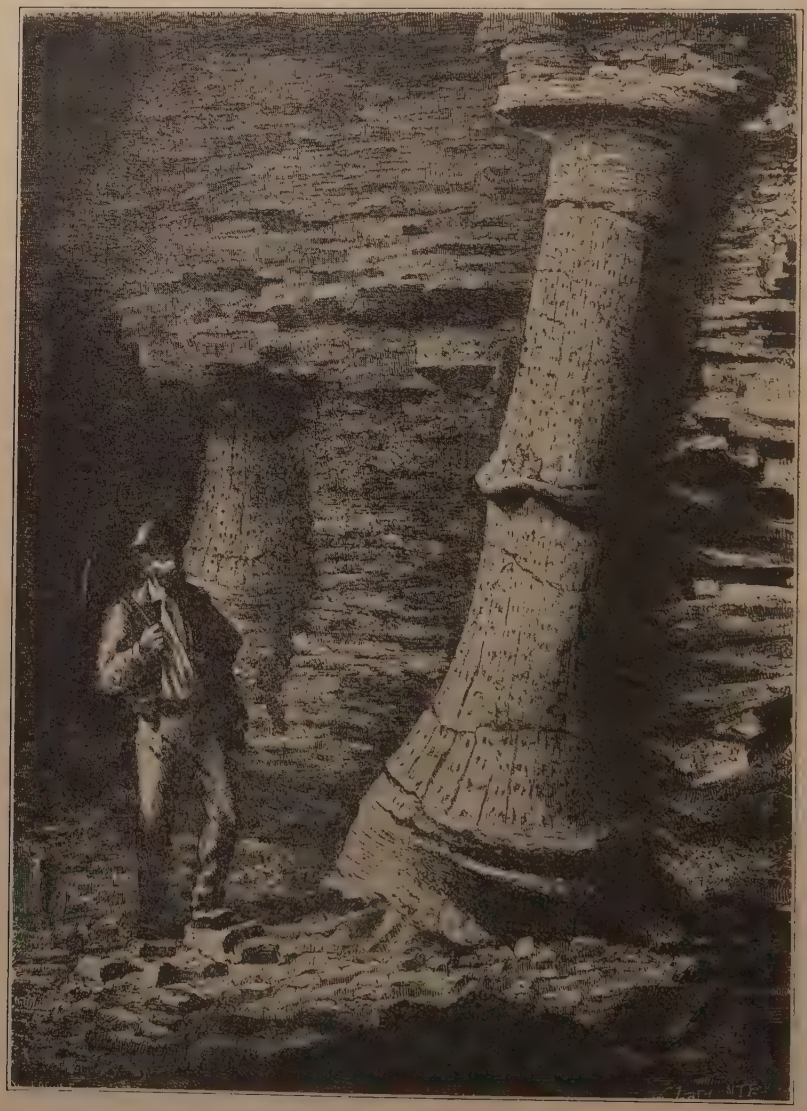


Fig. 4.—Sigillaria in Coal Mine at Saint-Étienne ("La Vie Souterraine").

thus prepared the earth for higher forms of organic life requiring oxygen, and then became extinct, when it could not get any further nourishment under the altered conditions of the atmosphere.

Thus it is generally agreed among those who have investigated the subject

that coal has been derived from vegetable matter, and the divergence of opinion mostly centres upon the mode of formation, as to whether it was formed on the site where the vegetation grew, or was accumulated in hollows at a distance, by means of water carriage. At this distant date it is extremely difficult to say how large and thick seams of coal were formed, and perhaps it is most reasonable to suppose that the thickest seams of coal have been buried from accumulations of vegetation in valleys and hollows, then probably, with moisture and with a rise of temperature and pressure after being buried, it was converted into coal.

Timber can thus be converted into brown coal or lignite as in the case in the Dorothea Mine at Clausthal where some of the old timbers of early workings were, in the disused levels, exposed to the action of water, impregnated with iron pyrites; when this timber which had been buried in the débris for two or three centuries was examined, it had a leathery appearance when it was wet, but when dried, it became hard and resembled the ordinary brown coal, with an external fibrous structure and an internal appearance of black, hard, pitch-like coal. The following table shows the gradual change in composition from wood to anthracite.

Substance.	Carbon.	Hydrogen.	Oxygen.	Disposable Hydrogen.
1. Wood (the mean of several analyses), .	100	12·18	83·07	1·80
2. Peat („ „) .	100	9·85	55·67	2·89
3. Lignite (the mean of 15 varieties), . .	100	8·37	42·42	3·07
4. Ten yard coal of the South Staffordshire basin, ...	100	6·12	21·23	3·47
5. Steam Coal from the Tyne, . . .	100	5·91	18·32	3·62
6. Pentrefelin Coal of South Wales, . .	100	4·75	5·28	4·09
7. Anthracite from Pennsylvania, U.S.A., .	100	2·84	1·74	2·63 *

The South Wales coal measure is a fair example of the conversion of bituminous coal into anthracite.

This seam of coal on its eastern side is good bituminous coking coal, but as it passes west, through Glamorgan, it is Welsh steam coal, from which part of the hydrocarbons have been eliminated, and when found in the neighbourhood of Swansea it is hard anthracite, the hydrocarbons having been completely extracted; this has been caused in all probability by heat from the incursion of igneous rock that has pushed its way near the coal measures, and by this action has gently distilled at a low temperature the volatile constituents.

"The basalt of Messner (Lower Hesse) overlies a thick stratum of brown coal, which shows an interesting series of alterations. Immediately under the igneous rock, a thin seam of impure earthy coal ('letten') appears, as if completely burnt. The next underlying stratum has been altered into metallic lustred anthracite, passing downwards into various black, glossy coals, beneath which the brown coal is worthless. The depth to which the alteration extends is 5·3 metres." †

During the time when this subterranean low temperature distillation of the coal was proceeding, the gases would find their way to the surface, and the oil and liquid products would be absorbed by sandstone or limestone, if in the vicinity; abundant proof of this is found in numerous oil fields, such as those

* Percy's "Metallurgy," Fuel, p. 268.

† Moesta, "Geologische Schilderung," Meissner und Hirschberge, Marburg, 1867.

of Scotland, where the coal measures have been pierced with numerous volcanic masses, and where the oil shale is mined and brought to the surface, and the oil is distilled from it in the form of paraffin. In the same district, quarrymen find in fissures of the rock, and in cavities, solid brown asphaltum from which the workmen make candles. It is a fact that in low temperature distillation of coal, oil instead of tar is formed.

The separation of carbon and oxygen is accomplished in the growing plant by means of chlorophyll, the green substance contained in the leaves or the lungs of the trees, retaining the carbon and giving up the oxygen, under the influence of light. Starch granules and sugar are first formed, which are plant food; these are converted into the woody fibre, or cellulose, forming the solid part of the tree. Chlorophyll is most active under the red or orange rays of the spectrum, and it is very probable that this would be the colour of the light from the sun penetrating the thick atmosphere, The starch and sugar are formed during the absorption of these rays by chlorophyll from the carbonic acid and moisture of the atmosphere.

When the vegetable matter with its resinous contents is buried, as in the coal measures, decomposition is resisted, and as the resinous matter preponderates in coal, the structural formation is preserved, while in those classes of coal where resinous matter is deficient, all traces of the original formation may be eliminated; this fact is illustrated by the deposits of amber found in some of the coal measures; some specimens have been found amongst the brown coal of Greenland, and in the coal measures of the island of Labuan, which have resisted all decomposing influences.

The resinous matter contained in coal is probably the product of the Lycopodium Spores, which are rich in hydrogen and are highly inflammable. This plant, together with the Sigillaria, is that from which most of the coal of the early formations is derived, see fig. 5.

Stopes and Wheeler state that:—"While special species of plants may develop special substances, like certain scented ethereal oils, for example, or may accumulate excessive amounts of certain substances, like the unusual amount of aluminium in the Lycopodineæ, yet in all higher plants, however different their species and individual peculiarities, even if they are as wide apart in geological time as the coal measures of the Palæozoic and the present day, the great bulk of the plant body is built up by the arrangement of certain fundamental tissues, which may be compared with the bricks of a building. Just as nearly every house has slates, bricks, woodwork, plaster, etc., in its construction, so nearly every plant has xylem (wood, lignified elements), parenchyma (soft cellulose-walled cells), phloem (soft-walled protein-containing cells), mesophyll (chloroplast-containing cells), epidermis, cork, etc., in its construction. Each of these types of tissue, according to the mass of its substance, the shape, quantity and position of its mass, determine, in conjunction with the others, the outer morphology of the various species. The substances composing each of these tissues have more or less definite and more or less known chemical composition. Hence, for example, the lignin composing the wall of a wood cell from a piece of timber is chemically like the lignin composing the wall of a wood cell from a leaf strand, though the latter may be less in *quantity*. Yet the chemical effect of a large number of small wood cells, easily overlooked individually as they are scattered through the opaque mass of coal formed of leaves, may yet be quite comparable in their effect on the composition of the coal as the larger mass of timber wood, which can be readily detected here and there in a mixed débris.

This fundamental fact—viz., that all vascular plants share the same chief types of all tissues—is the explanation of the gross similarity between coals of very different geological ages—for instance, Cretaceous or Tertiary coals, made

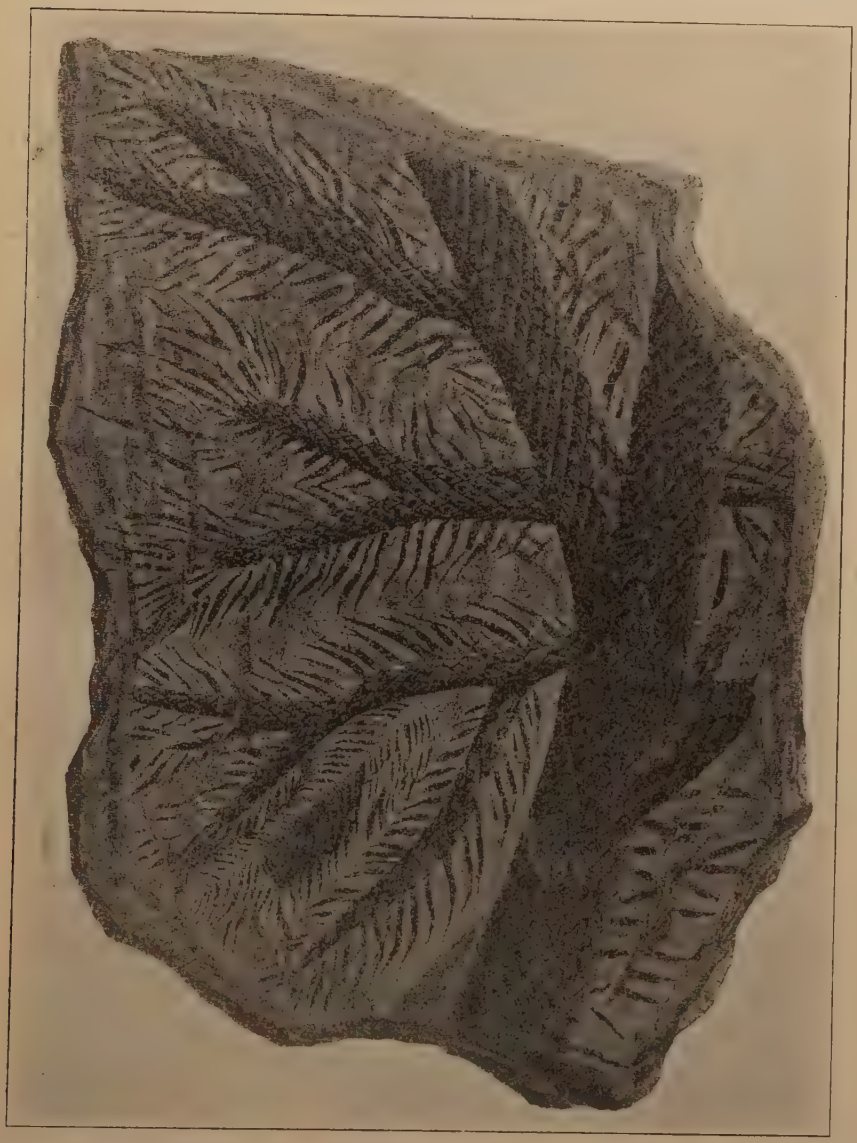


Fig. 5.—Lycopodium in Coal. Coal Measures of Aix-la-Chapelle ("La Vie Souterraine").

from the comparatively recent dicotyledonous flora, may be substantially identical in their response to the ordinary chemical tests, with coals of the Palæozoic age, though the *species* of plants forming the two coals are entirely

different. It is this fact which accounts for the disappointingly uniform results obtained by **Carnot,** who analysed specimens of coals collected by **Fayol,** each specimen formed from single plants generically different, and each identified botanically by the greatest palæo-botanist of his time, **Renault.** The analyses are given by **Carnot** as follows :—

Genus.	C.	H.	O.	N.
Calamodendron, . .	82·95	4·78	11·89	0·48
Cordaites, . . .	82·84	4·88	11·84	0·44
Lepidodendron, . .	83·28	4·88	11·45	0·39
Psaronius, . . .	81·64	4·80	13·12	0·44
Ptychopteris, . . .	80·62	4·85	14·53	
Megaphyton, . . .	83·37	4·40	12·23	
Commentry, Coal Seam 1, .	82·92	5·30	11·78	
„ „ „ 2, .	83·21	5·37	11·22	

The above genera of plants belong not only to different families, but to different classes of the vegetable kingdom ; hence they should have yielded the maximum differences in their resultant coal. But it will be observed that the analyses vary remarkably little and all are very similar to the analysis of the seam of the Grand Conche of Commentry, save for the important difference that they all have less hydrogen than the seam coal. In this connection it should be remarked that the specially selected plants consisted of trunks, while in the seam they were presumably mixed leaves, also in some quantity leaves having a higher hydrogen content than wood." *

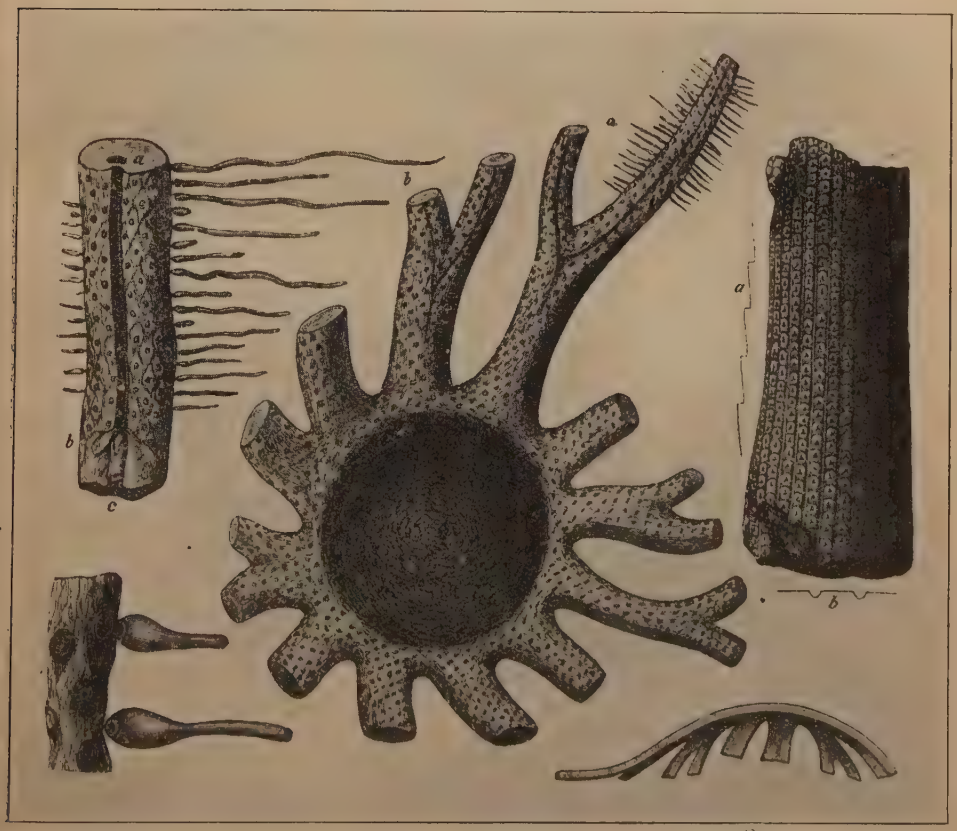
The chemical analyses of coal are extremely difficult, owing to the fact that most coals resist the ordinary solvents such as acids and alkalis. Pyridine, however, seems to be the best solvent hitherto discovered. The following table shows how little the harder classes of coals are attacked by acids or alkalis :—

Coal.	Reagents.†			
	Nitric Acid.	Sulphuric Acid.	Hypochlorite of Soda.	Potash.
Lignite.	Wholly decomposed ; solution light yellow ; residue white.	Wholly decomposed; solution pale orange-red ; residue white.	Much acted on ; solution deep red and thick, residue dark coloured.	Much acted on ; solution very deep red and thick, residue dark coloured.
Bituminous Coal.	Much acted on ; solution light greenish yellow ; residue dark brown.	Much acted on ; solution of the colour of a light port wine ; residue dark coloured.	Less acted on ; solution brownish-yellow ; residue nearly black.	Also less acted on ; solution light yellowish-green ; residue nearly black.
Anthracite.	Apparently unacted on ; the acid remained colourless and the coal black.	Little acted on ; solution light red : residue dark coloured.	Little acted on ; solution light yellow ; residue nearly black.	Very little acted on ; solution tinged with yellow ; residue nearly black.

* " The Constitution of Coal," Stopes and Wheeler, 1918.
† Percy, " Metallurgy," Fuel, p. 300.

With regard to the determination of the constitution of coal, the microscopical investigations of specimens submitted show with much more accuracy than analysis, some of the substances that have entered into the composition of certain coals; these investigations have proved that vegetable matter has largely entered into it, the woody fibre and bark being distinctly brought out (see fig. 6):—

Fig. 6.—Woody Fibre in Coal (Buckland).



Figs. 7, 8 and 9.—Fossilised Plants from Coal Measures (Buckland).

Specimens of fossilised plants have also been obtained from the coal measures, as shown in figs. 7, 8, 9, 10, and 11 ; how these specimens came to be fossilised

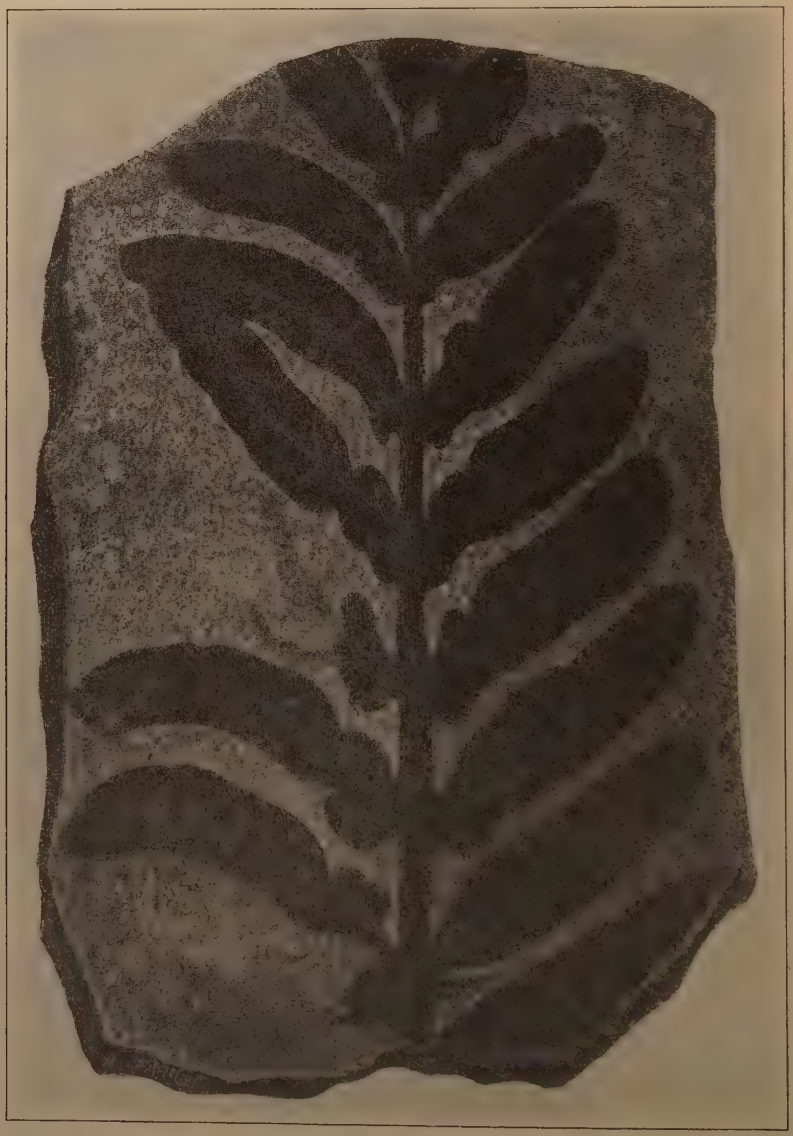


Fig. 10.—Fossilised Branch in Coal.—Coal Measures of Saarbrück (" La Vie Souterraine ").

without their shape being destroyed may be a question which it is difficult to answer. Conjecture may suggest that the coal in the process of formation at that particular spot was probably made up of leaves or mosses in a compact

mass, the specimen branch fell upon this mass, more of the same material immediately covered it up, when probably one of those cataclysmical occurrences took place, burying the whole mass rapidly ; this is also shown in fig. 4, where

Fig. 11.—Fossilised Branch ("La Vie Souterraine").

the stem of the Sigillaria is embedded in the mass of coal ; probably the mass of embryo coal was made up of leaves and wood which were old and dry, falling off the trees, and would thus soon develop into the stage of coal formation,

whereas these specimens of branches and leaves and trunks of trees that have been preserved in the natural state were probably laid down and covered up in a natural growing green state; if thus entombed, out of contact with the atmosphere, like the fishes and other fauna, they would be preserved intact until fossilised (see fig. 3).

Various other theories have been put forward accounting for the formation of coal from vegetation; one of the most remarkable is that of **Renault,** in an extensive work on the bacilli, fungi, and algæ in coal. He describes the mark of micro-organisms in a great variety of coals, and is of opinion that these micro-organisms destroy the plant form when decomposing it; he says, "Le temps ne paraît pas intervenir s'il n'est accompagné des véritables agents de décomposition des plantes; les cailloux de houille, quoique plus anciens, sont moins altérés que la houille même au milieu de lacquelle ils se trouvent." His conclusions may be correct, and account for the bed or mass of micro-organisms in the dead leaves, on which fell, the living branch above referred to, and illustrated in fig. 10.

The micro-organisms do their work only in the decomposing leaves and branches, so that if these were suddenly buried together with the live branch out of contact of air, the work of the micro-organisms would be arrested; they would be killed, probably fossilised, and the specimens preserved as we now see them.

Mother of Coal.—In bituminous coal in particular will be observed flaky thin layers of a black fibrous soft matter, which very much resembles wood charcoal in appearance, and soils the fingers; this is termed Mother of Coal, but a better name has recently been given to it, viz., *Fusain.*

A great deal of divergent opinion as to the formation of this substance has been expressed. Some authorities have held that it is the remains of forest fires that took place at that period, when the coal measures were laid down. Others have propounded the theory that it is the woody fibre of the plant, and that the hard shiny part of the coal is the bark, but against this theory is the small amount of this *Fusain* as compared with the quantity of bright coal, although Grand Eury (1882) exhibited a specimen of a piece of a *Cordaites* trunk in which the wood is represented by this *Fusain* and the bark by a ring of shiny coal around it. Probably there was no wood, but only soft pith, as in certain kinds of reeds or bamboo, the bark being the hardest.

The fact remains that this substance is certainly very different from the body of the coal in the hard, shiny portion, as analysis of the two from the same block of coal testifies. Karsten in 1826 noticed this difference, and gives the following analyses of the carbon contents * :—

Seam No. (Locality Carefully Noted)	Fusain. Carbon per cent. on ash-free substance.	Stone Coal. Carbon per cent. on ash-free substance.
1, ...	95·9	87·9
2, ...	95·2	81·0
3, ...	97·3	91·4
4, ...	91·5	59·8
5, ...	89·0	63·2
6, ...	79·1	41·0

* "Constitution of Coal," Stopes and Wheeler.

Green (1878) also made some investigations into this matter, and the following analyses give the percentages of carbon, oxygen and hydrogen in the ash-free, dry substances :—

	Better Bed Coal.		Haigh Moor Coal.	
	Fusain.	Bright Coal.	Fusain.	Bright Coal.
Carbon, . .	90·8	85·7	86·4	80·5
Hydrogen, . .	3·6	5·4	3·9	5·5
Oxygen and Nitrogen,	5·6	8·9	9·7	14·0

He also gives analyses of the ash of *Fusain* :—

	Better Bed Coal.	Haigh Moor Coal.
Silica, . . .	38·7 per cent.	36·1 per cent.
Alumina, . .	33·8 „	28·7 „
Ferric Oxide, . .	6·9 „	18·3 „
Lime, . . .	9·8 „	4·5 „
Magnesia, . .	2·8 „	0·7 „
Sulphuric Acid, .	7·7 „	7·6 „
Alkalis, etc., .	0·3 „	4·1 „

Apart from the specimen of Grand Eury, such specimens are very rare, and may have been formed under very exceptional circumstances. It seems, however, that this friable substance is the deposit of highly carbonaceous matter that has been left as it were by the mother liquor of the coal, when the bright coal was undergoing its fossilisation ; doubtless, gases would be given off, and under the great pressure of superincumbent masses of matter would, to a certain extent, be condensed, forming the bright coal ; all the water and liquid portions of the coal would be squeezed out through the interstices between the layers of coal. These gases, or liquids, would in their passage between these layers, become purified, and leave behind them their solid carbon contents, the fluid or gaseous hydrocarbons making their exits denuded of that portion of carbon left behind ; this would account for the wide difference in the analyses of the two substances. This process evidently has been carried to the extreme in the case of anthracite, where the total hydrocarbons have been extracted by heat, probably steam, and pressure, and where the gases could escape freely, destroying even the crystal formation of the coal itself. The layers of bituminous coal can be broken up into cubes, almost like galena, whereas, on the other hand, anthracite will give in many instances a conchoidal fracture, showing clearly that the cubical crystallisation of the coal has been destroyed. Nor do we find any of this *Fusain*, or Mother of Coal in anthracite, but on the contrary, it is clean to the touch, and bright.

Percy gives analyses of two different kinds of this *Fusain*, as described by Rowney :—

Composition Per Cent. of Fibrous and Granular Matter in Coal Dried at 100° C.

No.	Character.	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.
I.	Fibrous, . . .	82·97	3·34	6·84	0·75	6·08
II.	Granular, . . .	72·74	2·34	5·83		19·08
III.	Fibrous, . . .	73·42	2·94	8·25		15·39
IV.	„ . . .	74·71	2·74	7·67		14·86
V.	„ . . .	81·17	3·84	14·98		

I. From the common household coals of Glasgow Coalfields. II. From the Stonelaws coals. III. From Ayrshire coal. IV. From the splint coal, Elgin Colliery, Fifeshire. V. From the five foot seam, Elgin Colliery, Fifeshire.

CLASSIFICATION OF COAL.

ANTHRACITE.

Anthracite is black and but slightly soils the fingers. It is hard, shining and compact, will not ignite readily, burns without smoke, and does not flame; its specific gravity is between 1·30 and 1·40. Anthracite contains the highest proportion of carbon of all classes of coal; some specimens give as high as 98 per cent. carbon.

There is no doubt that anthracite is metamorphosed bituminous coal, as is evident from that found in the South Wales coalfield. In these coal measures the same seams of coal pass from bituminous or coking coal, containing hydrocarbons, to the anthracite non-coking coal, containing no hydrocarbons. Whether this metamorphosis was caused by heat from volcanic sources, or whether from some other cause, is a matter which cannot well be determined, because there are instances where heat has come in contact with bituminous coal, and has produced anthracite, but there are other cases where no volcanic heat has been near, and yet the coal has been converted into anthracite. The environment of the coal during the process of fossilisation may have been of such a nature as to allow of the free expulsion of the hydro-carbons (a) by water, (b) by pressure, or perhaps both (a) and (b) were responsible in an environment of a porous character, by washing and pressing the hydrocarbons out of the mass of the material undergoing coalification.

Anthracite is useless alone in the manufacture of coke, as it is non-caking, and under the strongest heat it does not seem to alter, if air is excluded. The author kept some anthracite peas (that is, small pieces) in a closed retort for 48 hours at a temperature of about 900° C., and found no appreciable change in it whatever, the peas came out of the retort apparently in the same condition as they were put in—clean and bright.

Anthracite, in some forms, decrepitates when heated, does not sinter, is brittle, and often has a conchoidal fracture. The cause of this decrepitation is not definitely known, and seems to be a feature of the South Wales variety, while that from Pennsylvania seems to be free from this defect. Some qualities are so liable to decrepitation that they splinter up in the furnace, and block up the ingress of air to the fire.

Probably the occlusion of gas or moisture in the interior of the coal is the cause, and upon heating causes the small explosions or splintering. There is a peculiar variety of anthracite which is iridescent, and is named peacock coal; it is found at Pottsville in Pennsylvania.

Anthracite mixed in powder form with good coking coal makes excellent coke, very solid and heavy, and a form of briquette, made by the author from waste anthracite dust, as a mode of burning this class of coal waste, and in order to get over the defect of decrepitation, is described in a future Chapter of this work.

Percy gives the following table for British and American Anthracites :—

Number.	Locality.	Specific Gravity.	Per Cent.							Composition per cent. exclusive of Ash and Water.†		
			Carbon.	Hydrogen.	Oxygen.	Nitrogen.*	Sulphur.	Ash.	Water	Carbon.	Hydrogen.	Oxygen.
57	South Wales, near Swansea,	1·348	92·56	3·33	2·53	..	..	1·58	..	94·05	3·38	2·57
58	South Wales,	1·392	90·39	3·28	2·98	0·83	0·91	1·61	2·0	93·54	3·39	3·07
58*a*	South Wales, Vale of Neath,	..	87·02	3·14	2·16	0·90	0·67	6·11	..	94·27	3·40	2·33
59	Pennsylvania, .	1·462	90·45	2·43	2·45	..	..	4·67	..	94·89	2·54	2·57
60	„	...	92·59	2·63	1·61	0·92	..	2·25	..	95·63	2·71	1·66
61	„	..	84·98	2·45	1·15	1·22	..	10·20	..	95·94	2·77	1·29

Percy also states that he once received a specimen of anthracite from Neath, South Wales, which decrepitated so much when he put it into the assay furnace in his laboratory, that the piece was "reduced to absolute dust."

BITUMINOUS COAL—COKING AND NON-COKING.

The application of the term "Bituminous" to coal is a misnomer, because coal does not contain bitumen, but the term is used to designate that class of coals which, under heat, become fusible and cake together; they occupy the place between lignites and anthracites. There are other classes of bituminous coals that do not cake together, but all classes burn with a smoky flame.

The coking coals of this class, when heated, emit bubbles of gas, which take fire, and burn with a bright white flame, and when such coal is heated in mass, it conglomerates and cakes together, forming a coke. If kept out of contact with air, in a retort, all the hydrocarbons will be distilled off, and the remaining coke will be coherent and solid, and in no way resembling the original

* The nitrogen, when not quantitatively determined, is included in the number indicating oxygen.

† Also of nitrogen and sulphur when separately determined.

coal. The fact being that the coal completely melts, and becomes amorphous, the bubbles of gas as they escape, after puffing up the coke leave hollow spaces, the size of which will be restricted by the weight of charge in the retort, but as the coke does not remain very long in the plastic state, the resultant coke is spongy throughout.

Very little is definitely known as to the cause of caking in one class of coal and its absence in another. The fact remains, that as we approach the lignites at one end, and anthracite at the other, the coals are non-coking. The caking or coking coals occupy the central positions. It is probably the volatile constituent that is the cause -that is, the proportion of hydrogen in the coal that determines its caking quality, but this is not constant. It is a well-known fact that the best coking coal loses this power of coking, if long exposed to the atmosphere, probably on account of its losing hydrogen and absorbing oxygen.

In the process of coking, during the period of destructive distillation, the caking or coking quality goes off, to a certain extent, tar and pitch being lost.

For example, if some powdered anthracite which is absolutely non-coking be taken and mixed with pitch or coal tar and placed in a heated retort out of contact with air, a piece of excellent hard coke will result, after the pitch or tar has been distilled off, and the residual carbon has bound together the grains of anthracite, but the tar used must be of a pitchy nature. Coke made with certain proportions of pitch and anthracite has been so hard as to have a metallic ring when struck. Percy has formed a table showing the organic constituents of caking and non-caking coals :—

	I. Non-Caking, Rich in Carbon.		II. Caking.			III. Non-Caking, Rich in Oxygen.			
	1	2	3	4	5	6	7	8	9
C.	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00	100·00
H.	4·75	4·45	5·49	5·85	5·91	6·34	6·12	6·04	5·99
O. N.	5·28	7·36	10·86	14·52	18·07	21·15	21·23	22·55	23·42

The proportion of hydrogen in excess of the amount required to form water with the oxygen, or the disposable hydrogen in these coals, respectively, is as follows :—

I. Non-Caking, Rich in Carbon.		II. Caking.			III. Non-Caking, Rich in Oxygen.			
1	2	3	4	5	6	7	8	9
4·09	3·53	4·13	4·04	3·65	3·70	3·47	3·22	3·06

" Hence it appears that there is no essential connection between the proportion of disposable hydrogen and the property of caking, for the proportion is nearly identical in Nos. 1 and 3 and in Nos. 6 and 5, which are non-caking and caking respectively. When the proportion of the disposable hydrogen much exceeds the maximum stated in the foregoing table the caking quality disappears. Thus a variety of cannel coal in which the disposable hydrogen

amounts to nearly 10 per 100 of carbon, yielded when heated in a covered crucible a slightly fritted carbonaceous residue, which could be easily crumbled between the fingers."—*Percy*.

As far back as 1857, Marsilly found that all caking coals lost their coking quality after being heated for a short time to 300° C. The same effect is produced, more slowly, of course, by the exposure of coking coal to the air. The author found that excellent coking coal from Durham, exposed to the atmosphere as powder, lost its coking property in less than one month, and the finer the comminution the more rapidly the coking quality is lost. Coal, therefore, destined to make the best coke should be put into the coke oven immediately it is raised from the pit. Anderson ("Chemistry of Coke") gives some figures bearing on this matter in the following table :—

	Ell.	Main.	Splint.	Gas.	Virgin.	Kilsyth Haughrigg.	Bannockburn Main.	Kilsyth Coking.
Relative coking power before heating, ...	4	4	3·5	3·5	4	9	15·5	16
Loss in weight on heating, per cent. on dry coal, . .	9·5	16·2	16·2	21·8	17·7	13·1	7·3	6·4
Result of coking test on the heated coal,	Chiefly a dull earthy coke; the rest powder.	The residue after coking just cohered and no more.				A dull coke, not swollen.	Good coke, but of dull appearance.	

In the above experiment the coal was heated to 300° C. in a current of dry carbon dioxide, with the results shown above.

Anderson accounted for the above facts by the presence of a resinoid compound which was capable of being extracted by a solution of potassium hydroxide, and gave this as the reason for the coherence of the coke in the Ell, Main, Splint, Gas and Virgin coals, these compounds having been destroyed by heat (volatilised without much residue), accounting for the result in the table above.

Stopes and Wheeler criticising this theory of Anderson's state :—

"There are several objections to this theory. The compounds extractable from coal by alkaline solutions are undoubtedly ulmin compounds, and whether or no they can be regarded as of 'resinoid' character, they are not volatile. Moreover, their presence in coal in any quantity has been found by several observers to have a detrimental effect on the coking property of the coal (compare **Mahler** (1892), **Dennstedt** and **Bunz** (1908), **Boudouard** (1909), and **Charpy** and **Godchot** (1916)), so that they cannot be 'coking constituents.' Harger (1914) gave a more likely explanation of Anderson's results when he suggested that strongly coking coals contain 'resinous' compounds which, on heating at a low temperature, yield a smaller quantity of a substance fusible at a higher temperature, this latter substance being responsible for the binding of the coke."

Anderson also obtained a definite melting temperature for true coking coals—viz., 317° C.—when heated in an atmosphere of carbon dioxide, and found that active gasification did not take place until a temperature of 337° was attained.

Percy also relates that the coals of South Staffordshire, of non-caking quality, will produce coherent coke if rapidly heated in a closed vessel to a high temperature, but they do not melt in the sense that the true coking coals do, but retain their shape. The author has seen coal of this description coked, the piece of coke appearing almost of the exact outward shape of the original coal, whereas in a true coking coal, the shape would be entirely changed, the whole piece melting and swelling up under the heat.

The coking power of a coal is generally obtained by experiment, by ascertaining the weight of silica sand it will combine with, to form a coherent coke.

Coals are often mixed to produce good coke. One may be deficient in carbon and rich in gas, another rich in carbon and poor in gas. When these are mixed in the proper proportions, the requisite quality of coke is obtained.

Cannel Coal is a variety of bituminous coal very rich in disposable hydrogen, and was very much in demand some time ago for the manufacture of gas; it burns readily with much flame. Its name is a corruption of candle, because coals of this nature burn like a candle; they are homogeneous, of a black, or brown black colour, do not soil the fingers, and generally give a conchoidal fracture, resembling hard pitch. Whitby Jet is a species of this class of coal. It is capable of taking a fine polish, and in fact, some of the surfaces of this coal when mined have a very high polish. This coal does not coke; it seems to be a solid hydrocarbon, leaving, after destructive distillation, very little coke residue, besides ash. It produces very rich illuminating gas, in large quantities, from 10,000 to 12,000 cubic feet per ton. It is the antithesis of anthracite as regards analysis:—

	Boghead Cannel.	Pennsylvania Anthracite.
Volatile Matter, .	71·06	3·96
Coke, ...	28·94	96·04
Fixed Carbon, . .	7·10	89·74
Ash, ...	21·84	6·30
Sulphur, . . .	0·24	0·585

Lignite, or brown coal, is of more recent formation than anthracite or bituminous coal, and is supposed by some to be an intermediate between wood and coal or "the first stage in the formation of true coal"; for instance, the stage of pitch peat, and lignite are very much alike, and in some cases lignite resembles the non-caking coals of the carboniferous period. It is generally of the tertiary period.

Zincken wrote a comprehensive treatise on this coal and calls it "the fossil accumulations of more or less carbonised remains of plants occurring in the Tertiary formation." *

Lignite is found compact, also earthy, and woodlike in appearance and structure, and often developing into a schistose or slaty appearance. It is conchoidal in fracture, or sometimes uneven, and in colour from yellow to dark brown and black; it is of a dull, shining or greasy lustre; it is generally

* Zincken, "Physiographie der Braunkohle."

saturated with water even after long exposure to the air. Probably it is very hygroscopic, and this is proved by thoroughly drying it and afterwards exposing it to the atmosphere. It will absorb moisture to about the same extent as previous to being desiccated.

Powdered lignite does not coke, but in some qualities it is so permeated with resin that it will cake together on being heated, but no coherent coke can be obtained from it. Some varieties of this coal are rendered practically useless as a fuel by reason of the large quantity of iron pyrites they contain; often on exposure to the air spontaneous combustion takes place owing to the heat produced by the oxidation of the pyrites.

Composition of Lignite.—Reynault gives the table of analyses for lignites of the Tertiary period shown on page 32.

Every specimen Reynault first heated to 120° C. for half an hour, in order to expel hygroscopic water, which he found was completely removed *in vacuo*, or at a temperature a little above 100° C.*

Lignites are found in almost all countries all over the world, and it is very probable that these coals have attained their final character, on account of having been formed out of vegetable matter quite distinct from that which obtained during the carboniferous period. They had grown in a later age, under different atmospheric conditions, and would therefore never yield ordinary coal.

Weathering of Coal.—When coal is exposed to the atmosphere it undergoes a change—that is, it absorbs oxygen. The oxygen combines with a portion of the carbon and hydrogen of the coal, forming thereby carbon dioxide and water, while oxygen also enters into combination with the sulphur in the coal, thus diminishing considerably its calorific value, and, in coking coal its coking or caking quality. This is very much accelerated by an elevation of temperature and moisture, and, where iron pyrites is present in some quantity, may lead to spontaneous combustion.

The weathering of coal has occupied the attention of a great number of investigators, whose conclusions do not always agree; Richter and Rider state that when coal is left exposed to the atmosphere in heaps, for 9 to 12 months, "it undergoes no sensible change in any respect," but they state that if heated at a comparatively low temperature a change is effected as described under the heading of bituminous coal (p. 28, *infra*).

The former conclusion must be erroneous, and according to Percy,† Fleck made some investigations on the weathering of coal. In 1856 a large quantity of each of six kinds of Saxon coal was reduced to powder, and a portion of each analysed. The remainder of the lumps of coal, from which the powders had been derived, were kept until 1865 in a case containing the chemico-technological collection at the Polytechnic Institution in Dresden, and analysed after the lapse of the comparatively long period of 9 years. The results are recorded in the table shown on page 33.

Percy, in making comments upon the foregoing table of Fleck, says:—"Now, if portions of the *same samples* of the coals referred to in the preceding table had been analysed in 1856 and 1865, it would have been found that in some instances a large proportion of the organic substance of the coal would have disappeared, for the inorganic matter constituting the ash could not have

* Percy, "Metallurgy," Fuel, p. 311. † Percy, "Metallurgy," Fuel, p. 291.

Table of Tertiary Lignites.

Character of Lignite.	Locality.	Specific Gravity.	Composition per cent., exclusive of Water only.				Composition per cent., exclusive of Ash and Water.				Nature of Coke.
			Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Coke, per cent.	
Perfect Lignite.	1. Dax, South of France,	1·272	70·49	5·59	18·93	4·99	74·19	5·88	19·93	49·1	Pulverulent.
„	2. Bouches du Rhone, .	1·254	63·88	4·58	18·11	13·45	73·79	5·29	20·92	41·1	„
„	3. Hessen Cassel, . .	1·351	71·71	4·85	21·67	1·77	73·00	4·93	22·07	48·5	„
„	4. Basses-Alpes, . .	1·276	70·02	5·20	21·77	3·01	72·19	5·36	22·45	49·5	„
Imperfect Lignite.	5. Greece, . . .	1·185	61·20	5·00	24·78	9·02	67·28	5·49	27·23	38·9	Like Wood Charcoal.
„	6. Cologne, . . .	1·100	63·29	4·98	26·24	5·49	66·96	5·27	27·77	36·1	
„	7. Usnach (Fossil Wood),	1·167	56·64	5·70	36·07	2·19	57·29	5·83	36·88	..	
Lignite passing into Bitumen.	8. Elbogen, Bohemia, .	1·157	73·79	7·46	13·79	4·96	77·64	7·85	14·51	27·4	Intumesced.
„	9. Cuba, . . .	1·197	75·85	7·25	12·96	3·94	78·96	7·55	13·49	39·0	„
Asphaltum.	10. Mexico, . . .	1·063	79·18	9·30	8·72	2·80	81·46	9·57	8·97	9·0	

Fleck's Table showing the Action of Weathering on the Chemical Composition of Coal.

Kinds of Coal, all from the Carboniferous System.	Year in which the Analysis was made.	Percentage Composition of Coal dried at 105° C.				Percentage Composition, exclusive of Ash.			Hydrogen per 1,000 parts of Carbon.	
		Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Disposable.	Non-disposable.
		1	2	3	4	5	6	7	8	9
I. Hard, shaly coal from the Oppelt pit in Zaukeroda,	1856	67·173	4·630	11·458	16·739	80·768	5·567	12·965	48·856	20·069
	1865	47·219	2·814	14·979	34·988	72·632	4·398	22·970	21·024	39·528
II. Coal from the third seam of the Oppelt pit. (Is this not as much shale as coal ?)	1856	26·544	1·904	7·320	64·232	74·230	5·325	20·445	37·303	34·434
	1865	32·779	1·756	11·132	53·333	70·241	3·764	25·995	7·331	46·255
III. Coal from the second seam of a colliery (des Gühnéschen Werkes) in Niederwürschnitz, . . .	1856	81·573	4·477	9·473	4·477	85·396	4·687	9·917	40·365	14·520
	1865	80·300	4·650	13·569	1·481	81·510	4·720	13·770	36·793	21·114
IV. Soft, shaly coal from the Gückelsberg pit, . .	1856	87·825	2·663	4·670	4·842	92·295	2·798	4·907	23·669	6·646
	1865	86·217	2·653	5·160	5·970	91·434	2·822	5·744	23·010	7·853
V. Coal (Pechkohle) from Helbig & Co.'s pit in Oberhohndorf	1856	80·963	5·518	12·081	1·498	82·113	5·602	12·285	49·518	18·705
	1865	73·472	4·645	19·728	2·155	75·972	4·747	19·281	30·761	31·722
VI. Coal from the upper seam of the Segen Gottes pit in Zwickau, . . .	1856	75·747	4·881	15·570	3·802	78·740	5·074	16·186	38·748	25·692
	1865	76·363	4·166	16·555	2·916	78·658	4·272	17·070	27·168	27·130

increased under the conditions the coal had been preserved. But loss of organic matter to the extent indicated in some cases is incredible ; and the experiments were, doubtless, vitiated by the fact that the samples analysed in 1865 did not originally contain the same proportion of inorganic matter respectively as those analysed in 1856. No conclusion, therefore, can be drawn from the numbers in column 4. While the inorganic matter may be unequally distributed through a lump of coal, there is reason for believing that, generally, the composition of the organic matter in that lump is not subject to similar variation ; and if this be so, then satisfactory conclusions may be drawn from the numbers in columns 5, 6, 7, 8 and 9. Now, these numbers show that in every instance the relative proportions of the carbon and the disposable hydrogen had sensibly decreased, and that the relative proportion of the non-disposable hydrogen had sensibly increased, after the lapse of 9 years, and, consequently, that the coals had suffered corresponding deterioration in calorific value."

He then goes on to quote from the figures of the experiments made by Richter, with regard to the weathering of coal, which are very interesting from both a scientific and a practical point of view.

E. Richter, of the Mining School of Waldenburg,* operated on two varieties of lignite, one fibrous and woodlike in structure (I), and the other earthy (II.) ; their percentage composition was as follows :—

	I.	II.
Carbon, ...	55·97	53·64
Hydrogen, ...	5·65	5·32
Oxygen and nitrogen, . . .	36·02	32·84
Ash, ...	2·36	8·20
	100·00	100·00

No. I. contained 1·12 and No. II. 1·22 per cent. of hydrogen in excess of what is required to form water with the oxygen present—*i.e.*, of disposable hydrogen.

The following experiments were made :—

I. 10 grams, moistened and left in contact with atmospheric air over mercury, absorbed in 6 days 4·3 c.c. (cubic centimetres) of oxygen, and 3·6 c.c. of carbonic acid gas were produced.

II. 10 grams, treated in like manner during the same period, absorbed 4 c.c. of oxygen, and 3·11 c.c. of carbonic acid gas were produced.

Moist lignite, whether freshly mined or after having been long exposed to the air, was found to absorb oxygen.

Richter ascertained that 20 grams of various freshly-mined coals of the carboniferous system, when in the state of powder, and freed from dust by means of a sieve, absorbed from 2 to 9 cubic centimetres of oxygen from moist atmospheric air in the course of 24 hours. Absorption begins very soon and proceeds with proportionate rapidity. Varrentrapp had previously shown that carbonic acid gas is formed by passing a current of atmospheric air over coal at ordinary atmospheric temperatures. The change which coal undergoes by exposure to air is greatest at first ; and although, according to Richter, the power possessed by coal of absorbing oxygen becomes continually weaker with

* See his articles in Dingler's *Polytechniches Journal* for 1870, cxcv., 315 and 449 ; and cxcvi., 317, also in Wagner's *Jahresbericht* for 1870, xvi., 758-778.

time, it never entirely ceases. It follows, therefore, that freshly-mined coal should absorb oxygen more vigorously and more quickly than coal which has been exposed to the air. The action of oxygen upon coal is much accelerated by heat, even at temperatures not exceeding 70° or 80° C., and evidence of this fact will be found in the foregoing table, in which are recorded Richter' experiments on the subject. The cause of coal absorbing so much oxygen when freshly mined is due to the fact that its natural environment has gone, the pressure being released, the pores, so to speak, are opened on the surface of the lump, and oxidation then proceeds, but as the oxidised skin is not removed this protects to a certain degree the portion immediately underneath, and in this manner the process will be one of diminishing intensity. This the author proved in the coking power of a block of coal which was exposed to the atmosphere for several weeks; after clearing away the outside skin (the oxidised part) the interior was found to be very little inferior to that when freshly mined from the pit. On the other hand the powder of the same coal, exposed during the same period, was absolutely worthless from a coking point of view.

With regard to the experiments of Richter, the coal under treatment was kept heated, it will be observed, from 70° to 80° C., and exposed to atmospheric air and moisture, while the determinations were made, as to its composition, both before and after treatment; and it was also demonstrated that temperature was a factor in the process, by leaving some portions of the coal at the ordinary temperature of the atmosphere, while the rest was under the thermic treatment; both were afterwards analysed; it was thereby proved that the portions heated had absorbed oxygen, and that the other portion that was not heated had undergone no sensible change in composition. As coal is mainly an organic substance, its absorption of oxygen will produce carbonic acid gas and water, but this is not quite apparent at first, for when coal in powder form is heated to about 200° C., it gains weight rapidly—that is, oxygen is absorbed faster than carbonic acid gas is evolved; but after a time, the heat being continued, the coal begins to lose weight, and afterwards the weight becomes practically stationary—that is, the chemical composition of the coal remains constant. This may be accounted for by the reason given above, that oxidation becomes slower as the coating of oxidised coal increases, except in the case of powdered coal.

Richter has tried to determine whether any relation exists between the power of coal to absorb oxygen, and to absorb moisture from the atmosphere, and to this end upwards of one hundred experiments were made by him. His methods were to employ different coals and dry them at a temperature of 100° C.; they were then left in contact with atmospheric air, saturated with moisture at a temperature of 15° C. It was then ascertained that they had absorbed from 2 to 7·5 per cent. of water and that this property was in no way dependent as was supposed on the structure of the coal, but was nevertheless dependent upon its porosity. The bright, compact coals (Glanzkohlen) often absorbed three times as much as very loose, soft and tender schistose coals (Schieferkohlen) of an almost lamellar structure. But coal from the same seam over a very wide area absorbed the same amount of water in proportion, or showed only a very slight difference in its capacity for absorption. Richter also found that the quantity of oxygen absorbed by different coals under similar conditions is proportionate to the quantity of water they absorb:—"It is regarded as probable that the first stage in the absorption of oxygen is purely physical, like that of moisture, and that the condensation of the gas precedes its combination with the substances of the coal."

TABLE SHOWING THE CHANGES WHICH TAKE PLACE IN COAL WHEN IT IS HEATED TO FROM 70° TO 80° C., IN CONTACT WITH ATMOSPHERIC AIR AND WITH MOISTURE.*

	Treatment to which Coal was Subjected.	Chemical Composition of the Coal per cent., calculated exclusive of Ash.			Ash per cent. in the Coal.	Per 1,000 parts by Weight of Carbon.		Calorific Power of Ash-free Substance of the Coal.	Increase per cent. in		Decrease per cent. in	
		Carbon.	Hydrogen.	Oxygen and Nitrogen.		Disposable Hydrogen.	Non-Disposable Hydrogen.		Weight.	Oxygen.	Carbon.	Hydrogen.
I.	(*a*) Before heating, . . .	82·90	5·25	11·85	5·70	45·48	17·85	7922	..	..	..	..
	(*b*) After heating in a water bath during 14 days at from 70° to 80° C.,	81·94	5·06	13·00	5·37	41·92	19·83	7741	1·01	1·28	0·13	0·14
	(*c*) After heating during 14 days in water bath, but during the day kept constantly moist, . .	82·02	5·09	12·89	5·59	42·42	19·63	7762	0·98	0·17	0·08	0·11
II.	(*a*) Before heating, . . .	84·44	5·07	10·49	2·90	44·52	15·49	8084	..	..	..	..
	(*b*) After heating as in No. I. (*b*), .	83·49	4·85	11·66	2·90	40·37	17·73	7842	0·25	1·20	0·74	0·21
	(*c*) After heating. Moist as in No I. (*c*),	83·81	4·90	11·29	2·91	41·63	16·75	7893	0·14	0·82	0·52	0·16
III.	(*a*) Before heating, . . .	90·73	4·25	5·02	9·87	39·92	6·92	8508	..	..	..	..
	(*b*) After heating as in No. I. (*b*), .	88·80	4·07	7·13	9·31	35·82	10·02	8201	0·20	2·12	1·76	0·16
	(*c*) After heating. Moist as in No. I. (*c*),	89·01	3·96	7·03	9·28	34·60	9·89	8183	0·45	2·04	1·32	0·27

Nos. I. and II. were coking coals, but No. III. was non-coking (Sand Kohle), and did not yield coke, properly so-called. The coking power of No. I. (*a*) was estimated at 1·4, and that of No. I. (*b*) was 1·1. The coking power of No. II. (*a*) was estimated at 2·0, that of No. II. (*b*) was 1·6. Nos. I. (*b*, *c*), II. (*b*, *c*), and III. (*b*, *c*) did not sensibly differ from Nos. I. (*a*), II. (*a*), and III. (*a*), respectively, either in yield of coke or specific gravity. The calorific value of No I. (*b*), II. (*b*), and III. (*b*) was reduced by about 2·62 per cent., 3·61 per cent., and 3 per cent. (? 2·28 per cent., 3 per cent., and 3·61 per cent.), respectively. The coals operated upon by Richter were all from the carboniferous system in Silesia, and had previously stood for a long time in a loosely covered vessel.

* Percy, *Metallurgy*, p. 294.

† In estimating the relative coking power of coal, Richter used the following method :—One gram of the finely powdered, air-dried coal is mixed with a definite weight of silica, in the state of ground flint such as is prepared for potters, and put loosely into a platinum crucible, about 3 cm. deep, and 3 cm. wide, which, with the cover adjusted, is heated in the coal-gas flame of a single Bunsen burner so that its bottom may be about 6 cm. above the orifice of the jet, and the height of the flame regulated to about 18 cm. Heating is to be continued until flame-producing gases cease to be evolved ; when this is the case, the coke is carefully placed with its bottom downwards upon a piece of sheet-iron. A weight of 0·5 kg. is then cautiously applied to the top of the coke, which will either be crushed or resist the pressure, and remain entire. If the former should occur the experiment is to be repeated with mixtures containing always the same weight of coal, and, say, 0·1 gram less silica each time, until one is found which yields a coke just capable of resisting the weight of 0·5 kg. ; but if the latter should occur, the same course is to be followed, except that the silica is increased by 0·1 gram each time. The strongest coking coal of the Waldenburg district required the addition of 2·8 grams of silica to 1 gram of coal, in order to produce a coke of the necessary quality, and its coking power is therefore indicated by the number 2·8.

Coal is also capable of absorbing carbonic acid gas, which is confirmed by experiments by Richter :—" In a given time and under the same conditions, coal absorbs three times as much carbonic acid gas as oxygen, in volume. Coal, of which the absorbent power for oxygen has been so much reduced by exposure to the atmosphere that 20 grams of it scarcely take up 1 cubic centimetre in a day, absorbs in the course of a few hours its own volume of carbonic acid gas. When coal is completely saturated with carbonic acid gas, and then brought into contact with atmospheric air, the volume of the latter is increased by the evolution of carbonic acid gas, but is afterwards gradually reduced. If in this experiment, which, it need hardly be remarked, should be made in a glass tube closed at one end, and inverted over mercury, a little caustic potash or soda be introduced into the tube, the absorption of oxygen will take place fairly rapidly, and with correspondingly greater evolution of carbonic acid gas, which will combine with the alkali. Coal saturated with carbonic acid gas was during 36 hours under the receiver of an air-pump exhausted to 2 inches of mercury, when it was found that most, but not the whole, of the carbonic acid gas had been evolved ; and if the coal so treated be saturated with moisture, and again put into the tube, absorption of oxygen will occur as vigorously as in the case of freshly-won coal, whether caustic alkali be present or not ; the liberation of carbonic acid, which may be quickly detected, indicating that the absorption of oxygen was at first attended by the disengagement of carbonic acid gas, which, in the absence of a substance capable of combining with that acid, is again taken up by the coal itself. When coal saturated with carbonic acid gas is boiled for half an hour with water and then dried, so as to leave it still saturated with moisture, its original absorbent power for oxygen is completely restored ; but when coal which has lost its power of sensibly absorbing oxygen by long exposure to the atmosphere is placed under the air-pump, that power is somewhat revived, though not completely restored. From what precedes, it is inferred that the diminution in the absorbent power of coal for oxygen, resulting from long exposure to the atmosphere, is not due to the condensation in it of carbonic acid ; and that coal, which has been so exposed, does not, when in contact with air in closed tubes, produce carbonic acid gas, whereas in the experiments of Varrentrapp that acid is stated to have been always formed when a *current* of atmospheric air was passed over coal.

The oxidation of the organic substance of coal by atmospheric air appears to be generally impeded, rather than promoted, by the presence of moisture, if we admit that the results recorded in the last table, under the head, " Decrease per cent. in Carbon and Hydrogen," suffice to justify a conclusion on the subject ; for, in every instance, except one relating to hydrogen at the bottom of the last column, less of these elements was oxidised by contact with atmospheric air in the moist than in the dry state. But, on the other hand, the oxidation of iron pyrites in coal by atmospheric air is favoured by moisture if, indeed, moisture be not absolutely necessary to that action at ordinary temperatures. Richter found that coal poor in sulphur absorbed less oxygen in the moist than in the air-dried state ; and, on the contrary, that coal rich in sulphur absorbed less in the air-dried than in the moist state. Sulphate of the protoxide of iron, or ferrous sulphate, commonly known as *green copperas*, or green vitriol, is the first product of such oxidation, and sulphate of sesquioxide of iron or ferric sulphate is the second. On the face of coal, which has been for some time exposed to the air, as in the gate road of a colliery, or even in a loosely covered jar, yellow ochre-like spots having a strong, inky taste may often be observed, which consist of the last mentioned kind of salt, a salt certainly

very nearly allied to, if it be not identical with, the mineral species designated *copiapite* or *misy*, and having, according to Rammelsberg, the formula –*

$2Fe_2O_3, 5SO_3 + 12HO$, or $Fe_2O_3, 3SO_3 + Fe_2O_3, 2SO_3 + 12HO$.
[$2Fe_2O_3, 5SO_3 + 12H_2O$, or $Fe_2O_3, 3SO_3 + Fe_2O_3, 2SO_3 + 12H_2O$.]

Apart from coal containing iron pyrites, the action of moisture as shown above, retards oxidation by atmospheric air at ordinary temperatures, and water, therefore, is a useful medium for the storage of coal for the double purpose of preventing oxidation, and spontaneous combustion.

Spontaneous Combustion of Coal.—It is a well known fact that in some collieries the dust is highly explosive, being in a finely divided condition. Coal is also liable to spontaneous combustion, when that surrounding pillars in a mine has been cut away, allowing the full weight of the superstructure to fall on them, thus increasing the pressure, with a probable rise in temperature.

The finely divided coal, therefore, absorbs oxygen, even at ordinary atmospheric temperature, but in the mine this is rendered more violent owing to the higher temperature obtaining in the workings. Spontaneous oxidation of coal is, in plain language, "combustion of carbon with oxygen at a low temperature." When carbon is burned at any temperature, this same combustion takes place, and when sufficient oxygen is present carbonic acid gas is evolved. It is therefore a danger signal when the presence of carbonic acid gas is detected on the floor of the workings in a mine; the danger is increased when quantities of coal are stored, where iron pyrites are present in the coal, and moisture is admitted. On the other hand, where sufficient water is present to cover the coal no danger from oxidation or pyrites, or of the coal itself, will occur. The following table was prepared by Richters and shows varieties of coal from the carboniferous system in three classes, according to their degree of self-inflammability:

TABLE OF COALS ARRANGED ACCORDING TO DEGREE OF SELF-INFLAMMABILITY.

Degree of Self-inflammability.		Iron Pyrites.	Water.	Character of Coal.
		Per cent.	Per cent.	
Class I. Difficultly self-inflammable,	1	1·13	2·54	Easily friable.
	2	from 1·01 to 3·04	2·75	Very compact.
	3	1·51	3·90	Very compact.
Class II. of Medium self-inflammability,	4	1·20	4·50	Firm, schistose, bright.
	5	1·08	4·55	Hard, but very brittle.
	6	1·15	4·75	Moderately tender.
Class III. Readily self-inflammable,	7	1·12	4·85	Outwardly very like No. 1.
	8	1·00	9·01	Moderately tender schistose.
	9	0·83	5·30	Moderately soft schistose.
	10	1·35	4·85	Moderately soft schistose.
	11	0·84	5·52	Not stated, yielded only 2·5 per cent. of ash. From the same pit as No. 10, but from a different seam, remarkable for its self-inflammability.

* Rammelsberg's "Handbuch der Mineralchemie," 1860.

Gases, Liquids, Sulphur, Phosphorus, Iron, Etc., found in Coal.—Coal is seldom found pure, the most perfect example of freedom from foreign matter is the anthracite of Pennsylvania, often showing, upon analysis, practically pure carbon, up to 98 per cent. Coal generally contains foreign matter in the form of silica, iron, lime, sulphur, phosphorus, etc., and for any purpose, be it for combustion under steam boilers, for domestic use, or for making metallurgical coke, the purer the coal is the better for the consumer, as most of the deleterious substances are non-combustible, heavy, and thus are non-economical, and produce clinker and ash. This matter of the purity of coal is one that is of the utmost importance to the metallurgical coke maker, because the coke is selected by the iron-master upon analyses, for use in his blast-furnaces for the smelting of iron. The higher the percentage of carbon in the coke produced from the coal, the less quantity is required to reduce a certain quantity of iron-ore in the furnace: the coke has not only to possess a high percentage of carbon, but must be free from certain deleterious ingredients, such as sulphur and phosphorus, and otherwise be low in silica or other ash-forming matter. There are large collieries with excellent coke-making coals, but the presence of sulphur or phosphorus in too large proportion makes the coal unfit for use in iron production. Sulphur in coal is not looked upon with favour for any purpose, and numerous experiments have been tried from time to time for the purpose of eliminating sulphur from coal or coke, but as the sulphur is chemically combined, it is practically impossible to separate it, for even in the coking process, it not only finds its way into the gases given off in the process of carbonisation, but enters into the tar and remains in the coke. Sulphur is mainly present in the form of iron pyrites, which can be seen on the laminal faces of the coal, as bright, brass-looking scales, but sulphur is often contained in the body of the coal itself. The same may be said with regard to phosphorus. This latter mostly concerns the use of coal for coke manufacture, in its use for smelting iron, as almost all the phosphorus existing in the coke enters the metallic iron, where it is most obnoxious, lowering the quality and value of the iron for most purposes.

When coal is burned, a quantity of the sulphur and phosphorus is evolved with the products of combustion, but so tenacious are these elements that they still remain to a large extent in the ash. The following table shows the percentage of sulphur in the ashes of coals* :—

Coals of the Carboniferous System.	Ash in 100 pounds of Coal.	Sulphur in 100 pounds of Coal.	Sulphur in 100 pounds of Ash.	Sulphur in the Ash from 100 pounds of Coal.	Sulphur evolved in burning 100 pounds of Coal
	Pounds.	Pounds.	Pounds.	Pounds.	Pounds.
From Zwickau, .	7·360	0·789	9·464	0·696	0·093
From Zwickau, .	5·760	0·973	14·663	0·844	0·129
From Berthelsdorf, .	16·530	3·264	18·174	2·424	0·840
Anthracite coal from Flöha, . .	48·316	1·746	2·798	1·352	0·394

Iron and other metals are frequently found in coal; the former when found together with silica and lime tends to produce slags in the furnace; by the melting and fluxing together of iron, lime, and silica, a very fusible slag is formed, which soon stops up the air inlet between the bars of the furnace, requiring frequent poking and removal. Fuel with a large percentage of these matters

* Percy, "Metallurgy," p. 275 (Fuel).

gives rise to increased labour in firing and increased repairs to furnace walls, due to the scouring action of these fluxes, and the losses occasioned by the disturbance of the fire on the grate bars, resulting in the loss of fuel, thrown away with the clinkered ashes. Iron, when free from sulphur, is not deleterious in coke for blast furnace purposes, as it passes from the coke into the pig iron in the smelting operations, and by this means is a gain to the smelter; but the proportions of iron, apart from pyrites, in coal is so small as to be negligible to the smelter.

Traces of copper and arsenic are frequently met with in coal, but not in sufficient quantities to interfere with its use.

Water in Coal.—All coal contains a certain quantity of water, which can be driven off by heating it to about 100° C. When coal is freshly won from the pit, and is air-dried, a portion only of the water it contains is driven off, and this portion is designated "pit water"; the remaining portion, which is designated "hygroscopic water," may be in combination with the coal. When coal is desiccated at a temperature of 100° C., it will lose all its water, but being again exposed to the atmosphere it will re-absorb water, not, however, to the original extent. "A large lump of air-dried coal from Lower Silesia was found to lose 4·31 per cent. of hygroscopic moisture by desiccation at 105° C., while the same coal in particles of the size of linseed lost by the same treatment 3·92 per cent. The two parcels of coal were then put into a cellar, where the temperature was 8° C., and there left until they ceased to gain in weight, which occurred after the lapse of 36 hours, when it was found that the lump had increased 0·74 and the fine coal 0·83 per cent in weight. They were again dried at 105° C., when the lump lost 0·63 and the fine coal 0·79 per cent. in weight; and by a second exposure to the air and subsequent desiccation, the former increased about 0·52 and lost 0·55, and the latter increased about 0·80 and lost 0·81 per cent. in weight. The tendency of the dried coal to attract moisture was thus reduced nearly 0·2 per cent. by repeated desiccation, and in proportion to the diminution in hygroscopic quality the coal became more tender and friable." *

The following table shows the proportions of water in the fine slack and the round coal, as they came from the pit, after an exposure of 36 hours:—†

TABLE SHOWING THE PROPORTIONS OF WATER IN FINE SLACK AND LUMP COAL FROM UPPER SILESIA.

No.	Moisture per cent. in the Fine Slack (*Staub Kohle*) as it came from the Pit.	Moisture per cent. in the Fine Slack after exposure to the Air during 36 hrs.	Pit Water per cent. in the Fine Slack.	Moisture per cent. in the Lump Coal as it came from the Pit.	Moisture per cent. in the Lump Coal after exposure to the Air during 36 hrs.	Pit Water per cent. in the Lump Coal.
I.	7·036	5·887	1·149	6·774	3·050	3·724
II.	7·442	4·887	2·555	8·073	3·786	4·287
III.	5·996	4·210	1·786	5·264	2·069	3·195
IV.	6·798	5·332	1·457	6·566	2·048	4·518
V.	8·246	6·332	1·914	9·000	3·841	5·159
VI.	7·137	5·489	1·648	6·449	2·497	3·952

* *Die Steinkohlen Deutschlands und anderer Länder Europas*, by Geinitz, Fleck, and Hartig, Professors at the Royal Polytechnic School, Dresden, 1865, ii., 215.

† *Ibid.*, p. 216.

Nitrogen in Coal.—Nitrogen is always found in coal, and its content is generally between 1 and 2 per cent. It is generally found accompanying cellulose compounds, so that nitrogen is a natural constituent of coal. Therefore when coal is submitted to destructive distillation, the desire is to recover the nitrogen as ammonia, and this is done to a very large extent both in gas works and in coke-oven practice. But nothing like the total content of nitrogen can be thus recovered. Even when the whole of the hydrocarbons have been distilled off, there seems a great affinity between the nitrogen and the residual coke. If a 20 per cent. recovery is made in either gas works or coke-oven practice it is considered good. It is only when the coke is also reduced to gas that a further portion of the nitrogen content can be recovered as ammonia, as by the Mond Gas process, but the total percentage contained in the coal can never be recovered.

In some coals the nitrogen content will not develop into ammonia when the coal is distilled, but passes off as nitrogen. This is peculiar to some of the coals in the coal measures of Nottingham.

Dr. Knublauch, who was the chemist of the Cologne Gas Works, was the first to recover the nitrogen from the coal as ammonia, an account of which is given in the "Jr für Gasbeleuch," 1883, p. 440, and according to this authority the following table shows the total nitrogen contained in coal, and that which remains in the coke :—*

No.	Nitrogen contained in Coal.	Nitrogen contained in Coke.	Proportion of N to corresponding Weight of Coal.	Proportion of N of the Coal left in the Coke.
1.	1·612	·737	·508	31·5 per cent.
2.	1·555	·677	·480	30·9 „
3.	1·479	·774	·532	36·0 „

The nitrogen left in the coke is termed the carbon nitrogen ; that which comes over with the gas in distillation is termed ammoniacal nitrogen.

The nitrogen in coal varies very much as will be seen from the following quotation from Anderson and I. Roberts, in *Jour. Soc. Chem. Ind.*, p. 1015.

	Per cent.
Five samples of non-coking coals (from different seams) range from, ...	1·65 to 1·72.
Five samples of semi-coking coals (from different seams) range from, ...	1·79 to 2·02.
Three samples of strong coking coals (from different seams) range from, ...	1·93 to 2·11.
Two samples of semi-anthracite (from different seams) range from, ...	2·25 to 2·55.

These coals were from the Scottish coalfields.

* "Chemistry of Coke," Anderson, p. 94 (1904).

The same authority gives the nitrogen contents of some of the coals from the coal fields abroad, as follows:—

Coal from	Westphalia	shows 0·84 to 1·77	per cent. N.
,, ,,	Upper Silesia	,, 2·49	,, ,,
,, ,,	Ostrau	,, 0·90 to 1·76	,, ,,
,, ,,	England	,, 1·14 to 2·37	,, ,,
,, ,,	North America	,, 1·20 to 2·00	,, ,,
,, ,,	Lodna (Bengal)	,, 2·12	,, ,,
,, ,,	Kussinda (Bengal)	,, 2·23	,, ,,
,, ,,	Barakar-Begonia (Bengal)	,, 2·48	,, ,,
,, ,,	Müke (Kiushu, Japan)	,, 2·85	,, ,, *
,, ,,	Ohtsuji (Japan)	,, 3·00	,, ,,
,, ,,	Taku	,, 3·10	,, ,,
,,	Kanada	,, 3·10	,, ,,
,, ,,	Yamano	,, 3·53	,, ,,
,, ,,	Yubari (Hokkaido)	,, 3·62	,, ,,

Of the Indian and Japanese coals (all but Ohtsuji) give firm, hard, metallic coking cokes.

Careful experiments made by Dr. W. Carrick Anderson and I. Roberts,† on small samples of coal, show that the free nitrogen other than that resulting from occluded gas comes from the dissociation of ammonia taking place at temperatures over 500° C. A quantity of Scotch splint coal, in powder, weighing 3 grams, and containing 1·5 per cent. of nitrogen, gave the following distribution of the nitrogen as the result of distilling for three hours at 440° C. to 470° C. :—

Nitrogen found.	Grams.	Per cent.
In coke formed (= 1·93 grams),	0·03540 =	78·67
In the aqueous distillate as ammonia,	0·00476 =	10·58
In the tar (= 0·41 gram),	0·00455 =	10·11
Total nitrogen accounted for,	0·04471 =	99·36
,, ,, in coal used,	0·04500 =	100·00
Balance unaccounted for,	0·00029 =	0·64

* Calculated on dry organic matter.

† *Journal of Soc. Chem. Ind.*, 1899, p. 1,103, and "Chemistry of Coke," 1904, p. 95

CHAPTER II.

REFRACTORY MATERIALS.

The process of carbonising coal and saving the by-products having to be conducted out of contact with air in closed vessels at a high temperature, for the manufacture of metallurgical coke, the ovens used for this purpose have to be constructed with materials of a highly refractory nature, combined with other qualities, to stand the strain of expansion and contraction inevitable in the charging of the highly heated ovens with cold wet coal.

There is a variety of refractory materials to be had, but there are comparatively few that are suitable for the purpose of coke-oven construction, and that will conform to all the requirements of successful and economical working.

Fireclay has been, and still is, the chief material in use for this purpose; but it would be a mistake to think that all fireclay is equally suitable for the construction of these ovens, as will be subsequently shown. There is, perhaps, no other material used in industrial operations possessing so diversified a nature as fireclay. It is not like a metallic oxide with a definite fixed chemical composition, but is often found, even in the same bed, in different qualities and composition, which presents the difficulties encountered in determining the origin of clay, whether it is organic or inorganic. Some authorities have maintained that it is the residue from the detritus of igneous rocks, while others have been of the opinion that it is the humus of the decomposition of plant life. However, whether it is of organic or inorganic origin, in composition it is generally a silicate of aluminium, and the diversity of its composition the following illustration will show:—

Composition of Fireclays from Neighbouring Beds *

	I.	II.	III.	IV.	V.	VI.	VII.
Silica,	51·10	47·55	48·55	51·11	71·28	83·29	69·25
Alumina,	31·35	29·50	30·25	30·40	17·75	8·10	17·90
Oxide of iron (Fe_2O_3 ?),	4·63	9·13	4·06	4·91	2·43	1·88	2·97
Lime,	1·46	1·34	1·66	1·76			
Magnesia,	1·54	0·71	1·91	trace.	2·30	2·99	1·30
Waters and organic matter,	10·47	12·01	10·67	12·29	6·94	3·64	7·58
	100·55	100·24	97·10	100·47	100·70	99·90	99·00

* Percy, "Metallurgy," p. 87 (Fuel).

These results were obtained from seven samples of fireclay from seven different seams, all lying in close proximity to each other in the coal measures adjoining Newcastle-on-Tyne.

The ideal material for the manufacture of refractory bricks should possess qualities such as freedom from expansion and contraction, infusibility, retention of form and substance under heat, and easy manipulation in manufacture. There may not be any single native material possessing all these qualities, but by a judicious mixture of certain clays, a near approximation may be obtained.

Most native clays contain impurities which leave the finished article deficient in one or more of the qualities above mentioned; some clays will make good bricks that will stand very high temperatures, but will shrink very much when highly heated, or on the contrary, they may retain their substance and form, but will fuse at high temperatures; those clays possessing high percentages of alumina will be of the former class, while those of the latter class will be poor in alumina, but possess percentages of fluxing oxides.

The most important sources of fireclay are the *felspars*, combinations of alumina with the oxides of potassium or sodium and silica. *Granite*, *gneiss*, and *porphyry* contain variable proportions of felspar. *Orthoclase* or *adularia* is a potash-felspar, whilst *albite* is a soda-felspar.

The large deposits of *kaolin* or porcelain clay in Devonshire and Cornwall are the result of decomposition of the fine white granite rocks of this neighbourhood.

When these felspathic rocks are under the influence of water and carbonic acid gas, decomposition sets in with changes of temperature, the silicate of potash is dissolved and is soon washed out. This is very probably the process that was carried on during the carboniferous period of the earth's formation, when the atmosphere was heavily charged with carbonic acid gas and moisture, and an elevated temperature existed; these rocks were thus broken down, and a large quantity washed away into the rivers, lakes, bogs, and the sea. That which found its way into the bogs, and those areas where the plants producing the coal measures were flourishing, would form with the soil excellent plant food, as the potash would be absorbed, leaving the silicate of alumina, as it is now found beneath the seams of coal, as fireclay.

The process of felspathic rock decomposition is still proceeding, but perhaps at a very much slower rate than obtained during the period mentioned above. The weathering of felspar, according to Wagner, may be postulated thus -

1 molecule felspar, $Si_3O_8\ K\ .\ Al.$, or $\left.\frac{3\ Si}{Al\ .\ K}\right\}O_8$ gives, under the influence of water,

1 ,, porcelain clay, $2\ SiO_4\ .\ H\ .\ Al.$, and

1 ,, acid silicate of potash.

It is probable that according to this reaction and the setting free of the silicic acid, the latter may combine to form *chalcedony spar* and *opal*.

All clays are essentially silicates of alumina, and range in colour from pure white to orange, red, brown, and even black, and blue when burned, according to the amount of colouring matter they contain. Iron oxide is the principal ingredient which imparts colour to clay, and it at the same time disqualifies it as a good fireclay, since iron oxide combines with silica, forming very fusible silicates, and more so if potash, soda, or lime be present.

Clay as it is mined often contains free silica in the form of sand, and mica, which, for the manufacture of porcelain, is put through a process of cleaning, to extract these ingredients, when a fine white clay is obtained.

Fresenius treated the clays of the Duchy of Nassau, which are employed in the manufacture of pottery ware, by a process of lixiviation, to free them from sand, and found the following, according to Percy :—

	1	2	3	4	5
Sand,	24·68	11·30	8·91	7·74	6·66
Very fine sand or sand dust,	11·29	12·54	10·53*	12·19	9·66
Clay,	57·82	70·73	71·66	71·70	74·82
Water,	6·21	5·43	8·90	8·37	8·86
	100·00	100·00	100·00	100·00	100·00

1, was from Hillscheid; 2, from Bendorf; 3, from Baumbach; 4, from Grenzhausen; 5, from Ebernhahn.

These clays on analysis produced after drying at 100° C. :—

	1	2	3	4	5
Silica,	77·03	75·44	62·78	68·28	64·80
Alumina,	14·06	17·09	25·48	20·00	24·47
Sesquioxide of iron,	1·35	1·13	1·25	1·78	1·72
Lime,	0·35	0·48	0·36	0·61	1·08
Magnesia,	0·47	0·31	0·47	0·52	0·87
Potash,	1·26	0·52	2·51	2·35	0·29
Water,	5·17	4·71	6·65	6·39	6·72
	99·69	99·68	99·50	99·93	99·95

The next table is interesting as showing the different states in which the silica was found in the clays, dried at 100° C.

	1	2	3	4	5
Silica in the form of sand (*a*),	24·91	11·39	9·13	7·91	6·81
„ in the form of fine sand (*a*),	11·40	12·64	7·07	12·45	9·89
„ in the finest state of division carried over with clay (*b*),	20·64	23·37	0·00	9·27	1·59
Total silica as sand,	56·95	47·40	16·20	29·63	18·29
Silica in the state of hydrate,	1·39	1·06	1·05	0·91	0·98
„ combined with bases (*c*),	18·69	26·98	45·53	37·74	45·53
Total silica,	77·03	75·44	62·78	68·28	64·80

a. These numbers are somewhat higher than those previously given, because they are deduced from the clays dried at 100° C.; whereas the latter were deduced from the *air-dried* clays. (Ordinary temperature).

b. These numbers are found by subtracting the sum of the sand given under the other heads from the total quantity of sand stated in the table of analyses.

c. These numbers are found by subtracting the weight of sand and hydrated silica from the total weight of silica.

* This is too high, owing to some clay having been carried over in washing.

Kaolinite.—Kaolinite, so designated by the American mineralogists, Messrs. Johnson and Blake, is a natural crystallised hydrous silicate of alumina. The name given to this substance seems to be a corruption of Kaoling, the name of a certain mountain in China, where china clay was obtained. It occurs in the state of a scaly, crystalline powder, and when microscopically examined is found to consist of translucent, rhombic or hexagonal plates, which are flexible like mica, but are inelastic; they occur conglomerated in bundles, and separately. In their purer state they are pearly white, but are often coloured by iron and other matters. The crystals are marked on their faces usually with lines, formed by the edges of plates of superimposed crystals. The crystals are comparatively soft, their hardness ranging from that of talc to between that of selenite and calcite. The specific gravity is from about 2·4 to 2·63. The substance is greasy to the touch, and forms a plastic mass; it is decomposed by hot sulphuric acid, is scarcely acted upon by cold hydrochloric acid, is difficultly decomposed by hot concentrated hydrochloric acid, but is easily dissolved by strong solutions of either potash or soda; it is infusible except at very high temperatures. Messrs. Johnson and Blake state that they have examined numerous specimens of kaolin, pipe-clay and fireclays, and have found transparent plates or crystals in all of them, and most of them consisted almost entirely of such plates or crystals. They state that the clay from Diendorf (Bodenmais) in Bavaria was perhaps the finest divided of all the white clays examined, and seemed to be composed of masses of a white substance, opaque, or nearly so, by transmitted light, but which, under full illumination above and below, had the appearance of snow. These masses when immersed in water were almost completely resolved into transparent plates, very minute, of irregular shape, and scarcely more than 0·0001 inch in breadth. This also applied to all the finer clays of a plastic nature examined, even those of a dark colour from Stourbridge, a pipe-clay from Table Mountain, Tuolumne County, California; blue fireclay from Mount Savage in Maryland, and also others from America and elsewhere.

The difficulty in eliminating free silica from kaolinite, either by mechanical or chemical means, accounts for the difference in analyses of clays, and excludes therefore, the application of the possibility of assuming that kaolinite is exclusively the basis of all clays, or of obtaining a definite, uniform hydrated silicate of alumina.

Lithomarge, *pholerite* and *nacrite* are pearly substances of a micaceous character, the former resembling more the character of porcelain, and are practically of the same composition as kaolin, but are non-plastic; they are found in mineral veins, also in the nodules of ironstone. Lithomarge is often found coloured, red, blue, and other colours, as well as white; it forms the matrix of the *topaz* at the Schneckenstein in Saxony; a variety mixed with iron oxide occurs in Antrim, and is used as a flux in blast furnace work.

Another mineral, *halloysite*, is of the same composition as kaolin, except that it contains twice the equivalent of water which kaolin contains, and as certain specimens of this mineral have been known to lose half their water content on drying at 100° C., the author agrees with Messrs Johnson and Blake that the whole of these minerals are only different forms of kaolin. And since kaolin is a residue from an igneous rock it is consistent to suppose that the original rock from which each of these minerals has been derived may have held the several constituents differently; and the other fact must be taken into consideration, that as the kaolin is the result of a chemical reaction upon felspar of an indefinite composition, the reaction may have been in certain

cases arrested, from some cause or other, thus giving the diversity of results which we find at present. This would certainly account for the excess of silica in certain specimens.

The clay thus derived from the decomposition of the rocks may have remained where it was originally formed, or it may have been washed away, and mixed with various other kinds of matter of different specific gravities. These, on deposition, would form in still water, layers of coarse and fine material, the coarse or heavier particles would tend to fall first, while the lighter particles would be carried further forward and form a deposition of finer grade material, so that when it is considered that the clay may have been submitted to such a treatment, its varying composition is explained.

Plasticity of Clay.—The use of clay for the formation of vessels, bricks or other objects depends to a large extent upon its plasticity, and to this quality is largely due its extreme usefulness in the arts of pottery and brickmaking. Without plasticity it would be practically impossible to handle or form any of the various articles now made from clay. Messrs. Johnson and Blake were of opinion that this quality—plasticity—was due to the fineness of division of the particles composing it, and in support of this statement they state that the kaolinites which they examined, one consisted chiefly of crystal-plates averaging 0·003 of an inch in diameter and was not plastic; a second, nearly pure, which occurred in bundles of smaller dimensions, the largest crystal not exceeding 0·001 of an inch in diameter was scarcely plastic; a third, crystallised kaolinite, was a scarcely coherent unplastic substance; a fourth, kaolin, largely composed of 'prismoid' crystals, was scarcely plastic, though when rubbed between the fingers it was soapy to the touch; the kaolin of Bodenmais, and other clays, in which the bundles were absent, and the plates were extremely thin, were highly plastic. The first of the above-mentioned crystallised kaolinites yielded by trituration in an agate mortar a powder which, under the microscope, resembled perfectly the finer kaolins, and was highly plastic and sticky, after having been wetted with water. They also state that a clay may be of identical composition with another clay, but differ completely in degree of plasticity, and they suggest that the plasticity of a clay may be related to the form, and perhaps to the thickness of the plates of the component kaolinites. This is extremely interesting, because, as already stated, the plasticity of clay is one of its most useful and important features. With regard to the formation of the crystals or plates in the clay as stated by Johnson and Blake, the most plastic clays were those when the crystal plates were extremely thin, but this does not take us much further, nor does it account for plasticity. Is it not the fact that under the influence of moisture, and probably capillary attraction, this moisture is retained between the thin plates, which not only attracts the plates together, but lubricates them, so that they slide over each other with greater facility, and at the same time prevents them being drawn asunder, more than is the case with crystals composed of other forms, with their solid bodies and sharp angles and corners? The finer the division and the thinner the plates of the crystals, the more plastic will be the clay. This is further exemplified when two plates of glass are moistened and placed together.

It is therefore from this reasoning, that as the water or moisture is retained by capillary attraction, it is the more difficult to dry or desiccate the object made of finely divided clay, even as it is difficult to dry out the water between two plates of glass.

Clay is plastic when mixed with water, and when dried it becomes hard, but softens and regains its plasticity on being again moistened with water; but

when clay is dried and heated to a certain temperature, it loses its water of chemical composition ; it then retains its hardness and shape, although it may absorb large quantities of water. Once it passes the temperature which expels the water of chemical composition it cannot be softened again ; it is now changed in composition and it is no longer clay, but a ceramic.

When objects made of clay are dried and burned, they shrink, as they lose the water they contain, and what are called "fat" clays shrink more than "lean" clays. The fat clays are those distinguished by their plasticity and retain the water longer than do the lean short clays of less plasticity, probably for the reasons given above. The shrinkage may be, on the surface, from 14 to 31 per cent., and in the solid capacity from 20 to 43 per cent. When making objects of any kind to certain given dimensions, allowance is always made for this shrinkage, but this allowance is generally made to agree with the amount of heat to which the clay will be subjected, and to the duration of its application.

Therefore, in the case of fire-bricks burned at a certain temperature, should that temperature be less than that required to effect the maximum shrinkage, the brick will subsequently shrink when placed in situ, and submitted to a greater temperature.

The author has experienced this in the construction of a large furnace for copper smelting, in which a certain class of fire-bricks were used, which had not been subjected to the requisite maximum temperature in the kiln when they were manufactured ; some of them placed over the fire-place shrank to such an extent that they dropped entirely out of the arch in which they were built.

The hard burning of fire-bricks presents certain difficulties to the manufacturers when the clay from which they are made contains an undue amount of alkali, or iron oxide, which act as a flux, sometimes they lose their shape before the maximum temperature has been attained ; this often takes place in the burning of the commoner kinds of building bricks, and to obviate this, bricks are often under-burnt, and consequently are disintegrated by the weather when built into a wall.

The conditions appertaining to the proper kind of clay to be used in the manufacture of bricks, relative to shrinkage and complete vitrification of the clay, in order to render it permanent, must be taken into account in the judicious mixing of certain clays, so as to compensate against failure of the finished article for the purpose for which it was made. These difficulties multiply as the objects made increase in size, not only from the unequal shrinkage of certain parts, compared with other parts, but in the burning, as will be further shown subsequently when treating of the burning of bricks and other objects.

The shape given to certain objects made of clay will also be shown to have difficulties underlying it, as for instance an object which is made partly thin and partly thick ; the thin portion will have become thoroughly desiccated before the thicker, and may be perfectly vitrified throughout, before the thicker portion has been half finished, therefore the temperature to fire the interior of the thicker portion properly may damage the thinner if constructed of such clay as will not stand the heat necessary for the thicker portion. It is for these reasons that insistence upon intelligent chemical knowledge regarding the proper mixture and composition of clays is necessary if an article is to be produced that is reliable.

The author some years ago almost despaired of finding a manufactory where goods could be produced and guaranteed to stand a certain temperature, because manufacturers insisted upon using only their own native clay. This,

however, is a thing of the past and manufacturers now mix their clays with others in order to produce the required result.

Influence of Alkali and Metallic Oxides in Fire-Clays.—The direct action of an alkali or a metallic oxide, such as the sesquioxide of iron, upon a clay containing silica, is the promotion of the formation of extremely fusible silicates. This fact was well known in the black glass bottle industry, where a large quantity of clay containing one or other of these substances was used in the manufacture of glass for bottle making. Percy also states that he treated in a crucible in his laboratory a clay from Watcombe, near Torquay, in South Devon, which melted into a black glass, and had the following analyses :—

Composition of Watcombe Clay.

Silica,	57·83
Alumina,	20·55
Potash,	3·87
Soda,	0·56
Lime,	1·68
Magnesia,	0·97
Sesquioxide of iron,	7·75
Oxide of manganese,	Traces.
Carbonic acid,	0·90
Water, combined,	4·39
Water, hygroscopic,	2·13
Organic matter,	Traces.
	100·63

Dumas gave the following recipe for making common bottle glass :—

30–40	pounds	Varec,
160–170	„	lixiviated ashes.
30–40	„	fresh ashes.
80–100	„	*clay containing iron.*
100	„	broken glass.

The most fusible silicates that may be found in clay for brick making are those of the alkalies, sodium and potassium; the silicates of protoxide of iron and manganese are more fusible than the silicates of lime or magnesia, while the silicate of alumina is more refractory still. If by any means the silicate of the oxide of lead finds its way into clay or bricks, this very fusible ingredient will soon make itself known, and any operations in which lead is used in the furnace will tend to result in the formation of these fusible silicates and deterioration of the brickwork will then follow.

In pointing out these dangers as to the fusible silicates that are formed by the ingredients found in the clay from which the bricks and furnace materials are made, it is also an important matter to consider, in selecting materials for the manufacture of these goods, that a clay with a certain fluxing silicate as one of its constituents should be mixed with another clay that will counteract this and render the mixture of clays of such a character that the resulting bricks will be of a first-class quality.

While these fluxing silicates are very harmful when they are redundant, at

the same time they may be very beneficial when they are so subdued that their influence is no longer detrimental in the sense of causing the fluxation of the brick, but on the contrary, act as a binding medium upon the other ingredients of the brick, that would not be satisfactorily made without them.

A brick may be constituted of materials which, at the highest temperature of the furnace used in their manufacture, will not consolidate and form sound bricks; such materials are magnesite, or a clay, very high in alumina; the judicious addition of a clay containing some fusible silicate, which melts at a temperature much lower than that of the furnace or kiln in which the goods are burned, will act as a binding medium; by this means the manufacture of silica bricks is accomplished.

When clays are mixed, or when a native clay is used the component parts of which are not homogeneous, it is necessary that a very thorough mixing be given in the preparation of the clay for the manufacture of material for furnace construction, because, apart from the considerations enumerated above, such as fusibility, the question of cracking and disintegration when the materials are built into the furnace must be considered.

The author has seen some of the best quality of firebricks for standing all strains that they are subjected to in a coke oven absolutely ruined by the introduction into the oven of the coking charge in the form of wet coal sludge. These fireclay blocks had the appearance of crocodile skin, some of the cracks penetrating the block to a considerable distance. This fact rendered these fireclay goods unsuitable for this particular purpose, while they proved of the best quality when used for other purposes.

It is always desirable to have a chemical analysis when selecting a fireclay for any purpose, and the same may be said for brick and fireclay goods for furnace construction, but it should be noted that chemical analyses will not discover every fault in the brick as used for different purposes, such as referred to above, standing the effect of cold water on the surface, while at a very elevated temperature.

Inability to stand up to the foregoing treatment is sometimes caused by making the goods of too dense a nature—that is, using in their manufacture too large a proportion of raw clay, and probably clay making too fusible an agent, whereby the vitrification of the particles is too easily accomplished, so that the sudden cooling of the exterior produces a greater contraction on the surface than in the interior, the surface being torn asunder. The same action is performed in the manufacture of "crackle glass" objects; the glass blower, before expanding his glass in the mould to form the object of his manufacture, dips the bulb of molten glass in hot water; this contracts the surface of the glass by cooling it suddenly and contracting it, and cracks it to a certain depth; but the blower removes it from the water quickly, before the glass in the interior of the bulb has been chilled; he then expands it in the mould to the desired shape, with the surface all covered with cracks, thus imparting to the object a crackled or frosted appearance.

In order to obviate this defect of splintering or cracking of fireclay goods, the clay is generally mixed with certain proportions of burned fireclay and coke, which are ground to the requisite size, before the goods are made. These latter ingredients render the materials porous—that is, they are formed with a coarse grain, as distinguished from the absolute vitreous nature of a dense fused brick, and this renders them to a very large extent impervious to the sudden changes of temperature that the goods will be often subjected to in coke oven and gas works practice.

The manufacture of firebricks by machinery has the tendency to give them the undesirable quality of being too dense, owing to the pressure used in their formation, whereas those made by hand are generally thought to be more porous, although very often they are not so good in shape and form as those that are machine made.

The cement used in building them into the furnace ought to be composed of the same kind of fireclay as that used in the manufacture of the bricks. The author has often found good firebricks destroyed by the use of inferior clay as the building cement. The clay for this purpose should be selected and finely ground, in order that a level, close and firm joint may be secured, and in order to use it to the best advantage it ought to be soaked in water, previous to being used, for at least twenty four hours, then worked up into a suitable paste, care being taken that no ashes or lime become mixed with it, as these would cause a fluxing action at elevated temperatures.

Refractory Character of Clay.—In order to arrive at some formula regarding refractory nature of clays, Bischoff, Wheeler, and others worked out a formula for a refractory coefficient. The following account of this is taken from Havard:—

"Let Q be the refractory coefficient, the oxygen content of alumina a, of silica b, and of fluxes c, then

$$Q = \frac{a^2}{b\,c}.$$

Now Q in refractory material may vary between 2 and 14; a refractory coefficient from 2 to 4 means that the clay will make a third class firebrick; a coefficient of 4 to 6 a second class firebrick; 6 to 14 a first class firebrick. For instance:—

"*CLASS I.*—First Class Firebrick Clay from Altwasser:

Al_2O_3 = 36·30, oxygen content 16·92.
SiO_2 = 43·84 (chemically combined 38·94, sand 4·90), oxygen content 23·36.

MgO,	0·19	Oxygen content is 0·293 × 3 = 0·879.
CaO,	0·19	
FeO,	0·46	
K_2O,	0·42	
Loss,	17·78	

The oxygen content of the bases (protoxides) is multiplied by 3.

Refractory coefficient, $\frac{a^2}{b\,c}$ = 13·95

"*CLASS II.*—Washed Kaolin from Zettlitz in Bohemia.

Al_2O_3 = 38·54, oxygen content 17·96.
SiO_2 = 45·68 (chemically combined 40·53, sand 5·15), oxygen content 24·363

MgO,	0·38	Oxygen content is 0·467 × 3 = 0·401.
CaO,	0·08	
FeO,	0·90	
K_2O,	0·66	
Loss on ignition,	13·00	

Refractory coefficient, 9·49

"*CLASS III.*—Belgian Plastic Clay.

Al_2O_3 = 34·78 oxygen content 16·208.
SiO_2 = 49·64 (chemically combined 39·69, sand 9·95), oxygen content 26·457.

MgO,	0·41	Oxygen content is 0·778 × 3 = 2·364.
CaO,	0·68	
FeO,	1·80	
K_2O,	0·41	
Loss on ignition,	12·00	

Refractory coefficient, 4·21.

"*CLASS IV.*—Sedimentary Clay from Grünstadt.

Al_2O_3 = 35·05, oxygen content 16·334.
SiO_2 = 47·33 (chemically combined 39·32, sand 8·01), oxygen content 25·225.

MgO,	1·11	Oxygen content is 1·490 × 3 = 4·470.
CaO,	0·16	
FeO,	2·30	
K_2O,	3·18	
Loss on ignition,	10·51	

Refractory coefficient, 2·37.

"*CLASS V.*—Cassel Clay, under Brown Coal Beds.

Al_2O_3 = 27·97, oxygen content 13·035.
SiO_2 = 57·90 (chemically combined 33·59, sand 24·40), oxygen content 30·908.

MgO,	0·54	Oxygen content is 0·983 × 3 = 2·995.
CaO,	0·97	
FeO,	2·01	
K_2O,	0·53	

Refractory coefficient, 1·86.

"The refractory coefficient $\frac{a^2}{b\,c}$ is derived as follows:—The relation of alumina to silica, or $\frac{a}{b}$, divided by the relation of the fluxes to alumina, or $\frac{c}{a}$, is the refractory coefficient or $\frac{a^2}{bc}$. This method of determining the refractory coefficient is fairly accurate, for technical purposes. It cannot be exact, since it does not take into consideration the physical qualities, density, porosity, size of grain, manner of burning, and other factors which influence the refractoriness and degree of fusibility."

Refractoriness and fusibility also depend upon the treatment of the firebrick under heat, its environment, and place in the furnace or oven, the action of heated vapours and gases, or metals or their oxides, or alkalis. It may also depend upon the mode of manufacture, *e.g.*, whether pressure is employed or not, in the formation of the brick; whether the particles composing the brick are large or small. As Ries states, the coarser the grain the more refractory the material, but if of uniform grain and composition there would be no difference in the fusibility of either a coarse or fine grain sample; if, however, the fine grain were highly aluminous and the coarse grain were very silicious, such a composition would prevent any fluxing action between the clay and silica, and

thus would show that clay may fuse at a higher point than that which would be assumed from chemical analysis.

Chemical analysis therefore, cannot always be depended upon as a guide to the refractoriness or fusibility of fireclay, but is extremely useful when the other points are also taken into consideration and a calculation carefully made from the data obtained; special attention should be paid to the relationship between the several constituents and their behaviour towards each other under heat, and also how they will act under the circumstances of their environment in the furnace.

A step forward has been made in recent years in this direction, with respect to the design of furnaces for high temperatures where several kinds of firebrick, made from different materials, are placed in their respective positions to fulfil the object of their differentiation; this has been accomplished with great success in furnaces constructed for metallurgical processes, as in the acid and basic processes of iron manufacture.

Some clays are found in layers of different chemical composition, as in the old mine at Stourbridge, where three qualities of clay underlie each other; on the top is a clay rich in alumina, in the centre is one of medium content of alumina and silica, and at the base is a strong silicious clay. It is therefore probable that this clay has been deposited under water, the heavier particles of silica having gravitated to the bottom, while the more finely divided particles of alumina are found at the top, and a mixture of the two in the centre, but of an amorphous character; the top is also amorphous, as distinguished from the definite crystalline nature of the silicious portion at the bottom.

Particulars are given by Ries * of a characteristic American fireclay from the coal measures of Missouri. The St. Louis clay is course grained, of average tensile strength, 80 to 150 lbs. per square inch, air shrinkage 6 to 9 per cent., fire shrinkage, 4 to 8·5 per cent. Vitrification temperature, 2,300° to 2,450° F. Viscosity, 2,500° to 2,700° F. and is used for the manufacture of glass pots, zinc retorts, gas retorts and firebricks, and is stated to be a first class clay if the goods manufactured from it are not subjected to too high a temperature. The fusion point is Seger cone, 30 to 31. The average analysis is :—

	Mine run.	Washed.
Combined silica (SiO_2)	32	32
Free silica (SiO_2),	30	25
Alumina (Al_2O_3),	24	24
Ferric oxide (Fe_2O_3),	1·9	1·85
Ferrous oxide (FeO),	1·2	1·00
Lime (CaO),	0·7	0·7
Magnesia (MgO),	0·3	0·2
Potash (K_2O),	0·5	0·55
Soda (Na_2O)	0·2	0·10
Sulphur (S),	0·3	0.18
Sulphur trioxide (SO_3),	0·35	0·40
Water (H_2O),	10·5	10·0
Moisture,	2·7	3·0
Total fluxes,	5·5	4·8

For the purpose of comparison Percy gives the following list of fireclays—*a*, British, *b*, Foreign. According to their chemical analysis, it will be evident that they differ very considerably. He states that he has purposely included some *bad clays* for the comparison of their composition with good clays, "so that a clear indication may be afforded of the injurious ingredients of a clay. Although several of the analyses are incomplete and so far unsatisfactory, yet they are interesting as showing the relation between silica and alumina."

* "Clays," by H. Ries, Ph.D., New York.

TABLE SHOWING THE COMPOSITION OF BRITISH FIRECLAYS.*

No.	Locality.	Specific Gravity	SiO_2.	Al_2O_3.	K_2O.	Na_2O.	CaO.	MgO.	FeO.	Fe_2O_3.	MnO.	PO_5.	Water Combined.	Water Hygroscopic.	Organic Matter.	Remarks,
1	Stourbridge, Worcestershire.	..	65·10	22·22	0·18	..	0·14	0·18	1·92	..	..	0·06	7·10	2·18	0·58	
2	„ „	..	63·30	23·30	..	..	0·73	..	1·80	..	..	..		10·30		
3	Congreaves,	..	57·31	26·58	0·44	..	0·71	0·49	2·83	..	..	trace	8·52	2·26	0·44	
4	Brierley Hill, Staffordshire,	..	51·80	30·40	..	trace	..	0·50	4·14	..	..	..		13·11		
5	„ „	..	51·70	28·50	..	..	..	0·85	5·85	..	..	..		12·50		
6	„ „	..	45·27	28·77	..	..	0·47	..	7·72	..	..	..		17·34		
7	Glascote, near Tamworth,	..	50·20	32·59	2·32	..	0·36	0·44	..	3·52	trace	..	9·69	3·00	..	
8	„ „	..	49·40	32·80	2·24	..	not determined	0·42	..	3·87	trace	..	9·84	..	..	
9	Stannington, near Sheffield,	..	48·04	34·47	1·94	..	0·66	0·45	..	3·05	..	..	11·15	..	..	
9a	Edgemount, near Sheffield,	..	45·73	34·14	0·45	..	0·79	0·74	1·76	FeS_2 0·77	trace	..	10·17	4·45	0·70	Trace of titanic acid.
10	Edensor, near Derby,	..	48·08	36·89	1·88	..	0·55	trace	..	2·26	..	..	10·87	..	..	
11	Newcastle-on-Tyne,	2·519	55·50	27·75	2·19	0·44 with Cl and SO_3.	0·67	0·75	..	2·01	..	..	10·53 with trace of organic matter.		..	
12	Teignmouth, Devonshire,	..	52·06	29·38	2·29	..	0·43	0·02	2·37	..	..	..	10·27	2·56	..	
13	Poole, Dorsetshire,	..	48·99	32·11	3·31	..	0·43	0·22	2·34	..	..	..	9·63	2·33	..	

14	Dowlais, S. Wales,	..	67·12	21·18	2·02	..	0·32	0·84	..	1·85	..	..	4·82	1·39	0·90 with a little CO_2	
15	„ „	..	44·25	34·76	1·58	..	0·34	1·18	..	3·41	..	trace	8·56	2·89	3·17	
16	„ „	..	53·05	28·13	4·19	..	0·17	1·20	..	2·48	..	..	5·82	2·20	2·82	Trace of sulphuric acid.
17	„ „	..	47·29	33·07	2·13	..	0·45	1·06	..	2·52	..	..	9·07	2·19	2·53	
18	„ „	..	46·26	32·14	2·11	..	0·73	1·21	..	2·99	..	..	8·79	2·77	3·46	
19	„ „	..	58·10	26·59	1·21	..	0·40	0·99	..	2·97	..	..	7·57	1·41	1·21	
20	„ „	..	53·99	28·66	1·76	..	0·31	0·88	..	3·27	..	..	7·41	1·52	2·46	
21	„ „	..	57·10	26·77	1·85	..	0·28	1·07	..	3·10	..	..	6·44	1·76	1·89	
22	Ireland,	..	79·40	12·25	..	..	0·50	..	..	1·30	..	..	5·20	..	..	
23	„	..	74·44	19·04	2·07	..	0·45	0·27	..	0·61	..	..	3·71	..	..	
24	Cornwall,	..	46·32	39·74	..	..	0·36	0·44	0·27	..	..	..	12·67	..	..	Some alkali included in the water.
25	„	..	46·29	40·09	..	..	0·50	..	0·27	..	..	..	12·67	..	..	Dried at 100° C.
26	„ 3 miles north of St. Austell,	..	47·75	38·11	0·73	..	0·16	0·02	0·69	..	..	..	12·54	..	trace	Dried at 100° C.

* Percy's "Metallurgy," p. 98 (Fuel).

Observations :—1. Best clay used by Messrs. Chance for glass pots. Brown, like a clay iron ore in colour. The silica is partly free, gritty sand being separated by washing. No sulphur was detected by boiling with nitric acid.

2. Best clay, such as is used at the works of Messrs. Chance.

3. Darker than No. 1. Silica partly free. No. 1 and this clay were fashioned into small prisms with sharp edges, and exposed in the same covered crucible to a very high temperature, when No. 1 became pale brown and No. 3 grey. No. 1 is decidedly more refractory than No. 3, which became more glazed on the surface. The two trial pieces adhered firmly together where they had been in contact. The potash was determined with great care. The results were as follows :—By fusion with nitrate of barium : No. 1 gave 0·20 per cent. No. 3 gave 0·43 per cent. By hydrofluoric acid : No. 1 gave 0·16, mean 0·18 per cent. No. 3 gave 0·45, mean 0·44 per cent. 8·09 grains of this clay were boiled with sulphuric acid in a platinum vessel. The insoluble residue weighed 4·955 grains, or 61·24 per cent. The total amount of silica found by fusion with alkaline carbonate was 57·31, so that the decomposition of the clay by sulphuric acid was not complete. The 4·955 grains of residue were boiled with a solution of carbonate of soda and a little caustic potash during two days ; the insoluble residue weighed 2·38 grains or 29·41 per cent., which in great measure was silica in the state of sand. [See p. 56.

Observations—continued :—

4. This clay was traced by Ruel of Holborn, refiner and crucible maker, and pronounced by him to be first-rate quality.

7, 8. This clay is made into firebricks by Messrs. Gibbs, Canning & Co. This clay has been used during many years at the School of Mines to make small crucibles for the assaying of iron ores, by the Swedish method. The iron exists both as protoxide and sesquioxide, but the proportion of the two oxides has not been ascertained. My friend, M. Leon Arnoux of Messrs. Minton & Co., China Works, informs me that it is extremely good for saggars.

9, 10. I received specimens of these clays from the late Mr. E. F. Sanderson of Sheffield, by whom they were used for cast-steel pots. They were weighed for analysis after desiccation at 100° C.

9*a*. Designated "Pot Clay," and used in making crucibles for melting cast steel in. It is said to be excellent in quality for that purpose. The air-dried clay lost 1·01 per cent. in weight by desiccation at 100° C.

11. Colour grey, streak dull, very soapy to the touch. It constitutes usually the basement of each coal-seam. From Blaydon Burn Colliery in Tyneside. It is used for firebricks.

12. Light brownish-grey with small, dark particles (lignite ?) diffused through it. Used in admixture for Cornish crucibles. This clay occurs at Bovey-Tracey in association with lignite, and so called Teignmouth clay from its being shipped from that port.

13. Greyish-white, soapy to the touch ; used in admixture for Cornish crucibles.

14-21. All from Dowlais. The local name of the coal-seams with which the clay is associated is stated under each number. No. 14 is considered the best fireclay at Dowlais. Blaen Rhas, three coals and clay. No. 15, not generally considered good as a fireclay. From the level Tomo. No. 16, this clay melted down on the bridge of a balling furnace. Red coal. 17, Blaen Rhas little vein. 18, Coal clod. 19, Panty wain. 20, Lower, 4 feet 2. 21, Little Pins.

22. Small crucibles made of this clay were kept for hours with melted steel in them, without in the least changing form.

23. I believe this clay was from Howth, near Dublin.

24, 25. Said to be the finest china-clay in Cornwall. The two analyses are of the same clay by different men.

26. Lithia was detected by the spectroscope.

Geological Position of the Clays in the preceding Table :—The clays numbered 1, 2, 3, 4, 5, 6, 7, 8, 9, 9*a*, 10, 11, 14, 15, 16, 17, 18, 19, 20, 21, are all from the coal measures, that numbered 12 is of Miocene age ; and the remaining ones numbered 13, 22, 23, 24, 25, 26, are china or pottery clays, resulting from the decomposition of granitic feldspar.

In the foregoing table of British fireclays, No. 16 is the red clay from Watcombe, near Torquay in South Devon ; Percy states that when it was heated in a crucible in an ordinary assay furnace, it melted into a black glass, showing the powerful influence of alkalis in promoting the fusibility of fireclay.

THE COMPOSITION OF WATCOMBE CLAY.

Silica,	57·83
Alumina,	20·55
Potash,	3·87
Soda,	0·56
Lime,	1·68
Magnesia,	0·97
Sesquioxide of iron,	7·75
Oxide of manganese	Traces.
Carbonic acid,	0·90
Water, combined,	4·39
Water, hygroscopic,	2·13
Organic matter,	Traces.
	100·63

The influence of iron pyrites may prove detrimental to clay, if used for certain purposes, and if it occurs in large quantities the sulphur under heat will be evolved to a certain extent, especially near the surface of the brick, the iron being at the same time oxidised, forming black spots on the surface, but should the iron be in such amount as to combine with the silica, a very fusible silicate will be produced that will flux the brick.

The following analysis of the principal British fireclays was made by Sir Frederick Abel, F.R.S., at the laboratory at Woolwich, which shows the different amounts of iron and alkalis, and the influence they have upon the bricks made from the various clays. The clay from the Glenboig Star Mine, the author considers the best for firebricks and this is in agreement with the opinion of Mr. Edward Riley, F.C.S., who examined the fireclay and bricks made from it; his analysis is subjoined.

Analysis of British Fireclays By Sir Frederick Abel, F.R.S.

Description of Fireclay.	Silica.	Alumina.	Iron Peroxide.	Alkalis, Loss, etc.
Kilmarnock, . . .	59·10	35·76	2·50	2·64
Stourbridge, . . .	65·65	26·59	5·71	2·05
„ . . .	67·00	25·80	4·90	2·30
„ . . .	66·47	26·26	6·33	0·64
„ . . .	58·48	35·78	3·02	0·72
„ . . .	63·40	31·70	3·00	1·90
Newcastle, ...	59·80	27·30	6·90	6·00
„ . . .	63·50	27·60	6·40	6·50
Glenboig, ...	62·50	34·00	2·70	0·80

Analysis of Calcined Glenboig Fireclay by Edward Riley, F.C.S.

Silica, ...	65·41
Titanic acid, ...	1·33
Alumina, ...	30·55
Peroxide of iron, ...	1·70
Lime, ...	0·69
Magnesia, ...	0·64
Potash, with a little soda, ...	0·65
	100·97

Mr. Riley says: "My analysis of the clay from the Glenboig Star Mine shows that it is very free from bases, such as oxide of iron, lime, etc., that have a tendency to make the clay soften with heat. The potash present is much lower than I usually find in best fireclays. I have been using this clay in some experiments as a standard by which to compare other fireclays."

These fireclays of the Glenboig Company are very largely used in coke oven

Table showing the Composition of Foreign Fireclays.

No.	Country.	SiO_2.	Al_2O_3.	Alkalies.	CaO.	MgO.	Fe_2O_3.	Water Combined.	Water Hygroscopic.	Miscellaneous Observations and Particular Localities.
1	France,	63·57	27·45	..	0·55	traces	0·15	8·64	1·27	1. Yellowish; at the highest temperature of the Sèvres porcelain kiln it only frits on the surface. Beleu (Ardennes).
2	„ . .	69·42	18·00	..	2·00	3·27	0·95	6·28	2·24	2. Greyish-brown. Boulogne (Pas de Calais).
3	„ . .	44·50	53·00	traces	1·34	0·60	1·91	16·48	12·87	3. Grey plastic clay above the chalk. Used for saggars for porcelain. Condé, near Houdan (Seine-et-Oise).
4	„ . .	60·60	26·39	„	0·84	..	2·50	9·20	..	4. Infusible at the highest temperatures of the Sèvres porcelain kiln. White plastic clay, occurring in the upper fresh water beds of the Paris basin, Dourdan (Seine-et-Oise).
5	„ . .	49·20	34·00	..	..	..	..	16·40	..	5. White plastic clay. Used for crucibles employed in the treatment of ores of antimony. Echassières (Allier).
6	„ . .	46·50	38·10	..	traces	..	..	14·50	0·42	6. Used for saggars for porcelain. Gaujac (Landes).
7	„ . .	66·10	19·80	..	..	..	6·30	7·50	..	7. Sandy, yellowish clay. Used for firebricks. Hayanges (Moselle).
8	„ . .	55·40	26·40	..	..	..	4·20	12·00	..	8. Dirty yellowish-white clay. Used for glass pots. La Bouchade, near Montluçon (Allier).

9	„ . .	52·55	26·50	..	3·00	1·50	0·55	15·00	1·55	9. Veined plastic clay. Used for porcelain saggars at Limoges. Malaise, near Limoges (Haute Vienne).
10	„ . .	52·10	36·00	..	5·00	2·00	1·80	..	..	10. Whitish plastic clay. Used for firebricks and porcelain saggars at Sèvres. Provins (Seine-et-Oise).
11	„ . .	42·00	38·96	..	1·04	0·17	0·85	16·96	2·27	11. Reddish. Used for porcelain saggars and Sèvres Retourneloup (Seine-et-Marne).
12	„ . .	58·76	25·10	traces	traces	2·51	2·50	11·05	1·45	12. Reddish, with scales of mica. Used for crucibles in which cast steel is melted at St. Étienne. Savanas (Ardèche).
13	Hessen-Cassel,	47·50	34·37	traces	0·50	1·00	1·24	14·00	0·43	13. Greyish. Used for Hessian crucibles. Gross-Almerode, Hessen-Cassel.
14	Bavaria, .	45·79	28·10	..	2·00	..	6·55	16·50	0·05	14. Deep grey. Used for Passau crucibles. Schildorf, near Passau.
15	Saxony, .	61·52	20·92	traces	0·02	4·97	0·50	11·70	2·70	15. Blackish, contains quartz. Used for porcelain saggars in the Meissen porcelain manufactory. Loshayn, near Meissen.
16	Bohemia, .	58·39	27·94	..	2·74	1·00	traces	10·00	0·49	16. White, very soft to the touch. Below the lignite. Used for saggars at Elbogen. Theuberg, near Carlsbad.
17	Austria, .	65·60	20·75	traces	1·65	traces	2·00	10·00	1·00	17. Pale dirty green, mixed with ferruginous spots. Used for porcelain saggars at Vienna. Gottveith, near Krems.
18	United States,	72·33	16·75	..	2·00	0·07	1·29	6·84	1·14	18. Greenish-grey, mixed with red spots. Used for porcelain saggars and glass pots. Delaware, 7 miles south of Newcastle.

construction, and in gas retort manufacture; the analysis of clay from their other works are also given below :—

Analysis of Gartcosh Fireclay, by William Wallace, Ph.D., and John Clark, Ph.D., Analysts and Gas Examiners to the Corporation of Glasgow.

Silica,	6·90
Titanic acid,	2·09
Alumina,	32·34
Peroxide of iron,	3·02
Lime,	0·37
Magnesia,	0·20
Potash,	0·06
Soda,	0·30
	100·28

They state that "The original clay is harder and more compact than most of the Scottish fireclays, and the loss of weight in burning is unusually small, and is accompanied by only a small amount of shrinkage. The specific gravity of the clay (water being 1) is 2·609, giving 162 pounds per cubic foot; and the loss of weight by calculation is 11·58 per cent. We find that the bricks weigh 131 lbs. per cubic foot, showing that they are dense and compact."

Analysis of Gartcosh Gannister Bricks, by William Wallace, Ph.D.

Silica,	87·06
Titanic acid,	Traces.
Alumina,	11·24
Peroxide of iron,	0·69
Lime,	Traces.
Magnesia,	Traces.
Potash,	0·61
Soda,	0·33
	99·93

He states: "This brick is made from a mineral which appears to be a soft sandstone. It is well adapted for withstanding the most intense temperature in all furnaces, with the exception of those in which it would come in contact with free alkali."

Analysis of Gartcosh Gannister Bricks, by John Clark, Ph.D.

Silica,	74·10
Titanic acid,	0·20
Alumina,	22·32
Oxide of iron,	2·20
Lime,	0·48
Magnesia,	0·34
Potash and soda,	0·38
	100·10

He states: "This is a very superior brick of a highly refractory character. In composition it is intermediate between the best qualities of ordinary fire-bricks and silica bricks, and in my opinion it possesses the more valuable properties of both."

Silica Bricks.—The use of silica in the manufacture of bricks dates from the year 1822, when Mr. Edward Young, of Newton-Nottage, Glamorganshire, formed a company for the manufacture of these bricks from material found at Dinas in the Vale of Neath, which is no doubt a millstone grit of the carboniferous system, similar to the gannister of Sheffield. It is almost pure silica, but from its proximity to limestone (in fact, it overlays it) a certain amount of lime is mixed with it, to the extent of about 5 per cent., with less than 1 per cent. of metallic iron or copper in the form of oxide.

It was first used, it is supposed, as a cement for the inside of the copper smelting furnaces in the neighbourhood. Its fire-resisting qualities resulted in many attempts being made to form it, with the addition of various clays and other binding materials, into bricks, but with little success until Mr. Young found out a method of making it into a brick by means of a mould in a machine. The rock is crushed and placed in the mould, with about 1 per cent. of lime mixed with it; this mixture is subjected to pressure in the mould, two moulds being fixed under one press. The mould is open at the top and bottom, like an ordinary brick mould, but closed underneath by an iron plate and above by a similar plate of iron; the upper plate fits the mould and acts like a piston, when pressure is applied; the bottom plate is then lowered and the brick pressed out on the iron plate, on which it is dried.

Being very tender and not fit to be handled as it possesses no plasticity, the workmen are required to handle the material and the bricks with gloves on their hands, to protect them from being lacerated by the sharp edges of the fragments of silica of which the brick is composed. When the bricks are dried, they are carefully transferred to the kiln, where they are burned for about 7 days at a high temperature, and about the same time is allowed for their cooling. They are manufactured in various special shapes to suit the furnaces in which they are to be used, for as they are of a very rough texture it is almost impossible to cut them to a desired shape. The fracture is very uneven, and the bricks expand by heat and do not subsequently contract, qualities which render them most useful in furnace construction, especially in the roofs, where a substantial and highly refractory surface is essential, but where no alkaline fumes or influence can approach them, or in positions where metallic oxides cannot come into contact with them.

Composition of Dinas "Clay."*

	I.	II.
Silica,	98·31	96·73
Alumina,	0·72	1·39
Protoxide of iron,	0·18	0·48
Lime,	0·22	0·19
Potash and soda,	0·14	0·20
Water combined,	0·35	0·50
	99·92	99·49

Bricks of a highly silicious nature are also manufactured from the waste of china clay from the decomposition of the feldspathic granite of Devonshire, by Messrs. Martin Bros., of Plympton, at Lee Moor.

These bricks are principally composed of angular fragments of white quartz, mixed with some of the inferior quality of china clay and moulded in the

* Percy, "Metallurgy," p. 147 (Fuel).

ordinary way. They are dried and fired in kilns, are of a pale brown colour, and when fractured show the fragments of quartz cemented together with the china clay with which they are made. They resemble Dinas bricks but are not so silicious, there being a very large addition of alumina, with a greater amount of iron, which gives the bricks a freckled and spotted appearance.

Composition of the Lee Moor Firebricks as ascertained by J. W. Mellor, D.Sc.

Silica (SiO_2),	72·32
Alumina (Al_2O_3)	23·54
Ferric oxide (Fe_2O_3),	1·00
Lime (CaO),	0·14
Magnesia (MgO),	0·11
Potash (K_2O),	1·88
Soda (Na_2O),	0·48
Titanic oxide (TiO_2),	...
Loss when calcined over 109° C.,	0·24

Refractory test.—Cone 32-33: 1710°-1730° C. (3110°-3146° F.); expansion 0·02 per cent.

It will be seen that the Dinas brick is bound, and the particles of silica fused together with lime, whereas in the Lee Moor brick the silica is bound with alumina. Therefore it will be apparent that these two bricks, although they are silica bricks, are really of a different nature, and can be used for various purposes. The latter is a much more solid and compact brick, and if very highly heated becomes vitreous on the surface and develops cracks, but is an excellent brick for coke-oven construction.

Fig. 12.—Graphite from Blast Furnace.

Graphite or Plumbago.—Graphite is carbon in an allotropic state, and is found in various parts of the world, often in association with igneous and metamorphic rocks. It can be produced in the blast furnace during the smelting of iron, and is then generally found in the slag in the form of shining crystals (fig. 12). Pure graphite is practically permanent at the highest temperature, provided that air is excluded; even when atmospheric air is admitted it burns away only very slowly. It is unctuous to the touch and makes a mark upon paper, from which latter property it derives its name—from the Greek word *grapho*, to write. The quality of native graphite that is used in the manufacture of writing pencils, often designated "black-lead pencils," contains no lead; this name probably was retained after the pencils had passed out of use, that were formerly made of very soft metallic lead which also makes a mark on paper, but is not so dark as that made by graphite.

Native graphite is very variable in composition; the graphite used for pencil manufacture is rather rare, the best being found at Borrowdale in Cumberland, but the graphite used as a refractory material is comparatively abundant. The state of the particles of the graphite and their conglomeration is the

distinguishing feature of that found in Cumberland; it cannot be described as being pure graphite, for there are purer qualities of graphite to be found, which are unsuitable for pencil manufacture.

The suitability of graphite as a refractory material for use in furnace work, crucibles and retorts, lies in its aggregation and in the composition of the foreign matter associated with it. The table on pages 64, 65 shows some analyses of graphite from various localities :—

Graphite, like carbon generally, is a good electric conductor and has a high thermal conductivity, but the diamond, another form of carbon, is otherwise. Graphite is found interspersed in granite and crystalline limestone in irregular masses of a more or less lenticular shape; that found in Cumberland at Borrowdale (the amorphous kind) is obtained from a dyke of *diorite*.

The graphite found in Ceylon is of the commercial variety, often in large pieces and of a definite crystalline formation; a similar crystalline variety is found with *mica* and *apatite* in the crystalline limestones of Canada, and in the State of New York. The Mines at Irkutsk in Siberia produce a large quantity of graphite, which is found in a granitic formation and is of a fibrous, columnar, and tabular crystallisation. Dava states that a large mass of the substance was found in these mines resembling wood in structure.

When found in iron, it is generally in that known as grey iron, and seems to be crystallised, for when white cast iron is dissolved in dilute sulphuric acid, a considerable proportion of the carbon is set free, and in the presence of nascent hydrogen, combines with the latter gas, forming hydrocarbons which are recognised by their strong smell; in some cases, these may be obtained as condensible oils. Another peculiar property is that when it is contained in grey iron graphite can be separated from the ordinary carbon—that is, if the iron is brought into solution without the decomposition of water, as by cupric chloride, which is decomposed with the production of ferrous chloride and metallic copper; the ordinary carbon separates as an amorphous sooty powder, while the graphite remains, with its characteristic crystalline character.* These two kinds of carbon, found in grey iron and white iron, simply result from the manner of casting. When cast in sand and slowly cooled the colour of the metal is grey, but when cast in thick iron moulds and chilled the iron has a white colour—that is, when the iron is slowly cooled the carbon to a certain extent forms crystals, but when quickly cooled it remains in the iron in an amorphous state.

The artificial graphite produced in gas retorts resembles the natural graphite in its refractory character, but is much harder and compact; both kinds are largely used for making refractory materials. Crucibles and retorts are made with large proportions of graphite for the purpose of rendering them more refractory, in order to stand very high temperatures and use for metallurgical operations. Crucible steel is generally melted in crucibles made of fireclay containing a large proportion of graphite.

The great difference between the diamond and graphite, charcoal, or coke is often attributed to the purity of the former, but with graphite practically approaching the impure diamond, the one is a good electric conductor, while the other is a bad electric conductor. This quality in the diamond, as compared with graphite of the purest kind, cannot be accounted for unless the specific gravity of the one is compared with the other; it is quite possible that the diamond being more compact is the better insulator, and that graphite may have the quality of being a better conductor by being made up of a conglomeration of crystals with moisture adhering to them.

* "Elements of Metallurgy," by Phillips and Bauerman, p. 139.

TABLE SHOWING THE COMPOSITION OF GRAPHITE FROM VARIOUS LOCALITIES (NAME OF THE ANALYST IN PARENTHESES).*

Locality.	Specific Gravity.	Per Cent.			Composition of Ash per cent.				
		Volatile Matter.	C.	Ash.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO and MgO.	Alkalies and Loss.
England, Cumberland, very fine specimen (Mène),[1]	2·3455	1·10	91·55	7·35	52·5	28·3	12·0	6·0	1·2
England, Cumberland, commercial sample, in pieces, (Mène),	2·5857	2·62	84·38	13·00	62·0	25·0	10·0	2·6	0·4
England, Cumberland, ditto in powder (Mène),	2·4092	6·10	78·10	15·80	58·5	30·5	7·5	3·5	0·0
England, Cumberland, ordinary specimen (Mène),	2·2379	3·10	80·85 Carbon and vol. matter (vol. = abbreviation of volatile)	16·05	..	..	..	..	..
England, Cumberland, Borrowdale (Karsten),[2]	..	..	86·7	13·3	36·5	26·7	(MnO_2 1·3) 18·1 and a trace of chromium	Lime and a trace magnesia 2·7	($Ti\,O_2$ 14·2)
Canada, Buckingham (Mène),	2·2863	1·82	78·48	19·70	65·0	25·1	6·2	0·5	1·2
India, Himalaya (Prinsep),	..	..	71·6	28·4	..	..	..	..	..
Ceylon, Crystallised (Mène),	2·3501	5·10	79·40 Carbon and vol. matter	15·50	..	..	..	..	..
Ceylon, crystallised (Prinsep),	..	..	94·0 to 98·8 Carbon and vol. matter	6·0 to 1·2	..	..	..	..	..
Ceylon, crystallised (Knapp),[3]	..	..	96·1	3·9	..	..	..	..	..
Ceylon, commercial (Mène),	2·2659	5·20	68·30 Carbon and vol. matter	26·50	50·3	41·5	8·2	0·0	0·0
Ceylon, unpurified (Prinsep),	..	..	63·8 Carbon and vol. matter	37·2	..	..	..	..	..
Ceylon, coarsely purified (Prinsep),	..	..	81·5	18·5	..	..	..	..	..
South Australia, Spencer's Gulf (Mène),	2·3701	2·15	25·75	72·10	..	..	..	..	..
South Australia, Spencer's Gulf (Mène),	2·2852	3·00	50·80	46·20	63·1	28·5	4·5	..	3·9
France, Pissie, Hautes-Alpes (Mène),	2·3280	2·17	72·68	25·15	..	..	..	..	..
France, Pissie, Hautes-Alpes (Mène),	2·4572	3·20	59·67 Carbon and vol. matter	37·13	68·7	68·7 ?	8·1	1·5	0·9[4]
France, Kaiserberg, Haut-Rhin (Ferstl),[5]	..	..	42·2	57·8	..	..	..	..	..
France, Brussin, Francheville, Rhone (Mène),	2·2029	0·28	92·00	7·72	..	..	..	..	..

France, Vaugnesay, Rhone (Mène),	2·1050	0·13	94·30	5·57	..	..	..	..	..
Sweden, Fagerita (Mène),	2·1092	1·55	87·65	10·80	58·6	31·5	7·2	0·5	2·2
Russia, Alibert Mine, Oural (Mène),	2·1759	0·72	94·03	5·25	64·2	24·7	10·0	0·8	0·3
Bavaria, Passau, commercial sample in powder (Mène),	2·3108	4·20	73·65	22·15	69·5	21·1	0·5	2·0	1·9
Bavaria, Passau, commercial sample in powder (Mène),	2·3032	7·30	81·08	11·62	53·7	35·6	6·8	1·7	2·2
Bavaria, Hafnerzell, near Passau (Berthier),[6]	..	..	Carbon and vol. matter 34·9	65·1	63·3	22·6	12·6	(Mg O) (1·5)	Traces of pyrites
Bavaria, Hafnerzell, near Passau (Knapp),	..	..	Carbon and vol. matter 47·1	52·9	..	..	..	..	..
Bavaria, Hafnerzell, near Passau, commercial sample (Ragsky),[7]	..	..	Carbon and vol. matter 42·0	58·0	45·5	43·3	11·2	..	..
Bohemia, Schwarzbach (Mène),	2·3438	1·05	88·05	10·90	62·0	28·5	6·3	1·5	1·7
Bohemia, Schwarzbach, First quality (Ragsky),[8]	..	..	Carbon and vol. matter 87·5	12·5	40·8	48·8	9·6	(Ca O) (0·8)	..
Bohemia, Mugrau, commercial sample in powder (Mène),	2·2279	2·85	90·85	6·30	..	..	..	..	..
Bohemia, Mugrau, commercial sample in powder (Mène),	2·1197	4·10	91·05	4·85	61·8	28·5	8·0	0·7	1·0
Bohemia, Prague (Mène),	2·3309	2·07	82·68	15·25	..	..	..	..	..
Moravia, Alstadt (Mène),	2·3272	1·17	87·58	11·25	..	..	..	..	..
Moravia, Hafnesluden (Ragsky),[9]	..	..	Carbon and vol. matter 43·0	57·0	86·4	12·2	1·4	..	..
Lower Austria, Zaptau (Mène),	2·2179	2·20	90·63	7·17	55·0	30·0	14·3	0·0	0·7
Brazil, Ceara (Mène),	2·3865	2·55	77·15	20·30	79·0	11·7	7·8	1·5	0·0
Madagascar (Mène),[9]	2·4085	5·18	70·69	24·13	59·6	59·6	6·8	1·2	0·6
Artificial from Creusot Ironworks, France (Mène),	2·5823	..	90·80	9·20	22·5	17·5	37·5	25·5	0·5
Artificial from Creusot Ironworks, France (Mène),	2·3981	0·30	81·90	17·80	42·5	9·0	8·0	40·5	0·0
Artificial from Ironworks, Vienne, France (Mène),	2·5830	0·15	88·30	11·55	..	..	..	..	..
Artificial from Ironworks, Givors, France (Mène),	2·4571	..	84·70	15·30	55·9	15·5	12·0	15·5	0·1
Artificial from Ironworks, Terrenoire, France (Mène),	2·4309	..	83·50	16·50	50·0	16·0	10·5	20·0	3·5
Artificial from gas-retorts (Mène),	1·8853	0·25	95·25	4·50	72·0	24·3	3·0	0·0	0·7
Artificial from gas-retorts (Mène),	1·6980	0·10	90·60	9·30	64·8	33·0	2·0	0·0	0·2

[*] Percy, "Metallurgy," p. 105 (Fuel, etc.).

All the analyses by M. Ch. Mène are taken from a table drawn up by him in *Comptes rendus* for 1867, lxiv., 1092. In these analyses the column on the right of that with the heading "Alumina," is headed "Fer," and it is not stated whether metallic iron or oxide of iron is meant, though in a following table by Mène on the composition of English plumbago crucibles, the column relating to iron is headed, "Oxyde de Fer," from which it may be inferred that in the accompanying table the same oxide is intended.

[2] *Archiv*, 1st series, xii., 93. [3] Percy, German first edition. [4] Probable typographical error in these numbers.

[5] *Jahrbuch der K.K geolog. Reichsanstalt*, 1854, p. 869. [6] Berthier, "Traité des Essais," i., 50. [7] Kenngott, "Uebersicht," 1854, p. 119. [8] *Ibid.*

[9] Kenngott, *Uebersicht der Resultate mineralogischer Forschungen*, for 1854, p. 119, published 1856.

[9] There is an obvious typographical error in these numbers which exists in the original and which I am unable to correct.

Alumina, Lime and other Refractory Substances.—Alumina is one of the most refractory substances known and will not melt except at very high temperatures, when it may be transformed into *corundum*. It has the peculiar property of being either basic or acid under certain circumstances. It is basic in clay and acid in *spinel*. This material would be of an ideal character for all refractory purposes if it were not for the great amount of shrinkage it undergoes by drying and firing. Although it cannot generally be used by itself, it may be combined with other substances to form excellent refractory materials. One of its chief sources is the mineral known by the name of *bauxite*, from being found near Arles, in the "*Colline des Beaux;*" it is also found in abundance in other quarters, in France, in Greece, in Syria, in India, and elsewhere.

The composition of bauxites will be seen from the following analyses*:—

Composition of Bauxite from Various Localities.

	I.	II.	III.	IV.	V.	VI.	VII.
Alumina,	58·1	57·6	55·4	30·3‡	33·2	64·24§	40·0
Sesquioxide of iron,	3·0	25·3†	24·8†	34·9†	48·8†	2·40	33·6
Silica,	21·7	2·8	4·8	..	2·0	6·29	2·0
Titanic acid,	3·2	3·1	3·2	..	1·6	..	..
Lime,	..	..	..	..	..	0·85	..
Carbonate of lime,	traces	0·4	0·2	12·7	(5·8‖)	..	..
Magnesia,	..	..	..	..	..	0·38	..
Sulphuric acid,	..	..	..	..	..	0·20	..
Phosphoric acid,	..	..	..	..	..	0·46	..
Water,	14·0†	10·8	11·6	22·1	8·6	25·74	24·7
	100·0	100·0	100·0	100·0	100·0	100·56	100·3

Authorities have not agreed upon the exact formula for bauxite, but Kenngott suggests the following, regarding it as a hydrate of alumina—

$$Al_2O_3, x\,H_2O.$$

With iron content it has been worked as iron ore. A very aluminous clay containing silica and iron is found at Almeria, in S.E. Spain, of the following analyses:—

	I.	II.
Silica,	26·84	15·17
Alumina,	35·42	48·26
Sesquioxide of iron,	9·81	7·67
Chloride of potassium,	1·62	0·82
Sulphate of calcium,	0·54	Traces.
Water,	26·65	27·21

This would evidently be a very suitable refractory material if its iron contents were not so large; under very high temperatures in certain circumstances it would fuse.

* Percy, "Metallurgy" (Fuel), p. 131.

† By difference.

‡ With silica and titanium.

§ With a very small quantity of titanic acid.

‖ Corundum, the limestone having been removed by weak hydrochloric acid (sic). Analyses I. to V., by Deville, *Ann. de Chim. et de Phys.*, S. 3, 1861, lxi., 321. The method of analysis is described with much detail, and should be consulted by the analytical chemist.

In the north of Ireland bauxite is found with iron ore below the basalt in Antrim, and is exported as aluminous iron ore of the following analyses :—

	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	TiO_2.	H_2O.	FeO.
Belfast ore (Tookey), .	9·87	34·57	27·93	0·91	0·62	3·51	19·36	5·08
Bauxite (Bell), . .	2·80	57·40	25·50	0·62	..	3·10	11·00	..

Corundum is a mineral consisting of nearly pure alumina, of which the *ruby* is the red or pink variety, and the *sapphire* the blue variety, while *emery*, the coarse variety, coloured with metallic oxides, is found in considerable quantities. Corundum is now used for various purposes, and forms one of the most valuable materials for very high temperature furnace lining, as it is only fusible by the oxy-acetylene blowpipe or the heat of the electric arc, when no fluxes are present. The composition of corundum is Al_2O_3, aluminium 53·2 and oxygen 46·8 per cent. generally, with ferrous oxide in the ruby and sapphire 1 to 4 per cent.; in emery the ferrous oxide reaches 8 per cent. and upwards; when the iron is found in larger quantities it probably exists as magnetite, in combination with the bauxite.

Magnesia.—Magnesia is practically infusible, except at the very highest temperatures, and bricks for the lining of furnaces have been manufactured from it and termed *magnesite* bricks.

A large quantity of this mineral is found and exported from Eubœa in Greece, and it is also found in Italy and India. Magnesite is the carbonate of magnesium, has a specific gravity of 3·056, and is of the following analyses :—

MgO, . . .	48 (Klaproth)	47·64 (Stroneyer).
CO_2, ...	49 „	50·75 „
Water and loss, . .	3 „	1·61 „
	100·00	100·00

When it is powdered and moistened with water it gives an alkaline reaction with litmus, but has a much weaker affinity for acids than the other fixed alkalis. Nevertheless, it completely neutralises them.

Magnesia was used some time ago, for the manufacture of crucibles, but owing to the difficulty in causing agglomeration of the particles, after calcination of the raw mineral, the crucibles lost their form, and often fell to pieces in the furnace, consequently their manufacture was abandoned.

The manufacture of bricks from calcined magnesite is now carried on, and considerable quantities are used for lining furnaces where a basic lining is required, and where silica bricks would be worse than useless.

In order to prepare the natural magnesite for use, it has to be calcined at a very high temperature, in order to drive off all the carbonic acid and reduce the residue to the minimum of contraction, otherwise when it is made into bricks, these would crack and contract when exposed to the high temperatures that they are intended to resist; but after carrying the calcination to this extent, the product will not agglomerate any more, and requires to be mixed with other

materials, or a portion of its own oxide calcined at a lower temperature, which forms a binding medium with the particles produced at the higher temperatures of calculation.

Magnesite has been found extremely useful in lining furnaces for steel manufacture, and other purposes requiring high temperatures, but the cost is one drawback to this material in some cases where it could be usefully employed.

Could it be made into retorts it would be most useful in a number of metallurgical operations where silicious material cannot be employed.

Dolomite, a mineral consisting of a mixture of lime and magnesia, is very largely used for furnace linings, and is often the source of supply for the pure magnesite by removal of the lime. This can be done by a method adopted by Scheibler, using sugar or syrup, which, with the dolomite, after the latter has been calcined, gives a saccharate of lime in solution, which is soluble in water; the magnesia being insoluble forms a precipitate and is separated by filtration. The saccharate of lime can be decomposed by passing carbonic acid through it in the ordinary way, the lime taking up the carbonic acid forming a precipitate of carbonate of calcium. The sugar can then be recovered for use again. Magnesium limestone is very variable in composition; generally it is $Ca\,CO_3$, $Mg\,CO_3$, a carbonate of calcium and magnesium, in almost equal proportions. When the lime is in excess the dolomite is not so good as when the reverse is the case, and the larger the proportion of magnesia to the lime the more refractory will be the material; for furnace linings complete calcination at a high temperature is necessary.

Chrome Iron Ore.—Ferrous chromite occurs as a mineral in regular octohedrons with a granular crystalline fracture, generally found massive. It is found in the North of Scotland (Shetland Islands), Norway, America, Russia, Turkey, etc., and is often accompanied by alumina and magnesia, amorphous ingredients. Generally it is found as $Fe\,Cr_2O_4$ but frequently it contains a larger amount of iron, $Fe_2Cr_2O_5 + Fe_3Cr_4O_9$. This mineral has been used for the purpose of lining furnaces with what is termed a "neutral lining." Open hearth furnaces, the bottoms of which are lined with this material, have proved very advantageous for the basic process of steel manufacture, especially where lime is used for the purpose of absorbing phosphorus from the metal. The lining proves not only infusible but practically impervious to the action of the materials contained in the charge, which would corrode a lining composed of dolomite. The method adopted is to ram the mineral, mixed with tar, in a heated condition into the bed of the furnace, and after it is well rammed and beaten down it is fired at a very high temperature. These bottoms so made are also in use for re-heating furnaces for basic steel ingots. According to Bauerman, the composition of the mineral is $-(Mg\,Fe)\,(Cr_2Al_2)\,O_4 = \left\{\begin{matrix}(Mg\,Fe)\,O\\(Cr_2\,Al_2)\,O_3\end{matrix}\right\}$, sometimes with Fe_2O_3, but its composition often varies very widely.

LIME.

Lime, *per se*, is one of the most refractory substances, but to apply it for the purposes required of a refractory material is a problem that up to the present has not been solved satisfactorily. It will stand the highest temperatures without sensible change, and is infusible. The difficulty with the material is agglomeration; this can be very easily accomplished in the first stage, that of

formation of bricks or other articles, with caustic lime after it has been hydrated, but when it is subjected to desiccation and subsequently exposed to a high temperature it splits up and disintegrates. Small pieces have been made and often successfully heated without splitting with the oxyhydrogen blowpipe flame for producing an intense bright light.

Lime crucibles have been successfully made, in small sizes only, but they have to be cut or carved out from a piece of well burned lime, kept absolutely dry, and used at once, before any damp can penetrate them. They will, if successfully made, withstand a temperature higher than any other material will; but, as stated above, no practical method has been devised for the production of permanent bricks or blocks or linings of this material for use in furnaces.

Zirconium Oxide.—*Zircon, Hyacinth, Jacinth, Jargoon*, composition Fe_2O_3 0·6 to 2·2, Al_2O_3 0 to 2·5, CaO 0·8 to 3·5 per cent., ZrO_2 66·3, and SiO_3 33·7 per cent.

Zirconia is a mineral found with silica as *hyacinth* and in *eudialite*, with titanic acid in *polymignite, æschinite*, and *cerstedite*, and with tantalic acid (to the amount of 3 per cent.) in *fergusonite*.* Zirconia was discovered by Klaproth in 1789, and was considered a rare earth until the large deposits were discovered in Brazil. Many experiments were conducted in Germany by Messrs. Krupp for the purpose of using it for hardening steel, and pure white zirconium oxide was produced in Germany free from silica, iron, and titania.

The Brazilian deposits are situated in the Caldas region, partly in the state of Minas Geraes, and partly in the state of São Paulo, about 130 miles north of the city of São Paulo, in the mountains, at an elevation of over 3,000 feet, on a plateau where certain thermal mineral waters of medicinal value are present, which were investigated by Orville A. Derby, F.G.S.† The mineral is named *zirkite*, and can be divided into two classes :—

1st. Alluvial, in pebbles analysing 90 to 93 per cent. zirconium oxide; the pebbles are known locally as "Favas;" they have a specific gravity averaging from 4·8 to 5·2.

2nd. In the zircon ore or zirkite, ranging in colour from grey to blue or black. The darker colour averages 80 to 85 per cent. zirconium oxide, while the lighter coloured may contain only 73 per cent. This ore has been investigated and found to consist of three minerals, viz. :—*Brazilite, zircon*, and a zirconium silicate, analysing about 75 per cent zirconium oxide. *Zirkite* has the peculiarity of being readily soluble in hydrofluoric acid, whereas *zircon* is not acted on by this acid, while to all appearance it has the same crystalline formation.

The ore is found in large outcrops on the western edge of the plateau. The deposits are not yet worked to any extent but prospecting operations have proved the vein in several cross-cuts. In some of the deposits of an alluvial nature, the ore occurs in the form of gravel embedded in a kind of reddish clay, This is mined, and the clay exposed to the sun to dry, and the zirconia gravel is separated by screening. As these deposits are far away from any railway the costs and difficulties of transport are great, as the only transport in these regions is the bullock cart, of very primitive design, drawn by as many as eight yoke of oxen, with a load approximating one ton of ore, over the mountainous roads. It is stated that this deposit is of vast extent, having been traced for a distance of fifteen miles, between Cascata and Caldas.

* Gmelin, "Chemistry," vol. iii., p. 337.

† *Quarterly Journal Geol. Soc.*, Aug. 1887.

A general analyses of " zirkite " ore, made in the laboratory of Dr. C. James, of Durham, New Hampshire, U.S.A., gave the following composition :—

Zirconium oxide,	78·78 per cent.
Ferric oxide,	2·03 „
Titanium dioxide,	0·70 „
Silica,	17·05 „
Alumina,	0·50 „
Manganese,	Trace.
Loss on ignition,	1·52 „

Pure *brazilite* will analyse with as much as 93 per cent. of ZrO_2. This mineral has been named commercially *zirkite* by the Foote Mineral Company of Philadelphia. The vice-president of this company, Mr. H. C. Meyer, visited the mines of Zirconia in Brazil in 1915, and from his observations and remarks upon these deposits (in a paper read by him before the Ceramic Society of Swansea, 1918), the information regarding these minerals and their application as refractories is obtained.

The mineral varies much in character, as is evident by the following samples on analysis :—

ZrO_2,	93·18	81·75	86·57	85·93	82·00	71·88
SiO_2,	1·94	15·49	2·50	9·35	11·38	25·31
TiO_2,	0·69	0·50	1·43	1·84	0·36	0·63
Fe_2O_3,	2·76	1·06	5·29	1·93	2·08	0·43
Al_2O_3,	0·64	0·85	1·00	0·36	0·62	0·15
MnO,	Trace.	Trace.	..	..	..	..
H_2O,	0·47	0·63	3·32	1·56	3·35	1·56

The other source of zircon is the silicate. There are large deposits of this mineral in the form of sand in Brazil. It is also found in Norway and Henderson County, North Carolina, U.S.A., at Pablo Beach, Florida, U.S.A., and in other localities. It is also obtained from the Florida and Brazil deposits as a by-product, and from the electro-magnetic concentration of the Monazite Sand.

Zirconite or zirkite has most remarkable refractory qualities. It has a high melting point, low coefficient of expansion and low thermal conductivity, and therefore makes good linings for furnaces. The pure oxide is much too costly for universal application, the costs of purification, extraction, etc., being heavy, which puts it at once out of reach for ordinary purposes, but " zirkite " is, however, when carefully selected and manufactured, a first class refractory, and tests have been made with it against magnesite bricks, with the following results :—" To determine the behaviour of the material when in contact with carbon at high temperatures, a brick was made a part of one side of the trough of a granular carbon resistance furnace, the rest of the trough being made of magnesite brick, all being backed up by firebrick. A pyrometer tube was put in so as to give the temperature of the surface of the brick, next the carbon resistor, and temperatures read with a Wanner pyrometer. In about one half-hour after starting the temperature was 1800° C. + or — 25°, and it was kept between 1,750° C. and 1,850° C., averaging 1,800° C. + or — 25° for one and a half hours. The furnace was then torn apart. The zirkite brick was just nicely red on the back (2½ inches from the resistor), while the magnesite bricks were much redder. From this and from the temperature of the firebrick backing, when felt from time to time, it was plain that zirkite has a considerably lower thermal conductivity than magnesite, and quite probably the lowest of any

available material that will stand 1,800° C. The brick when put in place had a slight crack, and this increased a little on heating, but not very badly. Magnesite bricks on both sides of it were badly cracked. A slight shrinkage was noted on the hot face, and the surface of the zirkite brick was slightly pitted and spongy. The magnesite bricks were considerably more acted upon by the carbon than the zirkite bricks, their surfaces being eaten away uniformly over $\frac{1}{8}$ inch. Hence, as regards the action of carbon on the hot brick, the zirkite brick appears to be superior to magnesite, but inferior to carborundum. The zirkite brick was not supporting any weight and only the inner face reached 1,800° C., but when the brick was picked up with a pair of tongs they sank into the hot face, under gentle pressure, to a depth of $\frac{1}{2}$ inch." This brick was made with a binder consisting of Warrior Ridge clay, and from these tests it seems with this binder 1,800° C. is the limit of temperature. Although not so good a refractory when manufactured into bricks with a binding medium as the pure oxide, nevertheless zirkite is a very useful material, and is being used for lining furnaces in the United States. The Foote Mineral Company state that a very satisfactory commercial process has been lately perfected for the manufacture of zirkite bricks, and various shapes are now being made to suit requirements; they state that the method of manufacturing zirkite bricks consists in first passing the ore through a crusher, and grinding to about 60 mesh in a dry pan, removing all particles running finer than 100 mesh by passing over inclined screens, and binding the resultant product with zirkite cement. About 50 per cent. of 60-mesh zirkite and 50 per cent. of zirkite cement constitute the refractory mass. This is made into a stiff mud with water and moulded in the same fashion as silica brick. "Green" zirkite bricks have to be dried very slowly as otherwise they develop air cracks. Furthermore, great care is required in setting them. The standard bricks are made on an average of 13 lbs. each. It is suggested to mix magnesite and zirkite to form a cheaper lining for furnaces. As this material is practically novel for furnace work, no doubt it may be very much improved upon in the immediate future, along the lines of combination with other suitable refractories for making the bricks free from their present defects, as will be gathered from the tests above described. The furnace operations of the future no doubt will demand refractories of a very high class, as processes in the arts are developing by means of high temperature treatment. The chief requirement is for a suitable and dependable material for constructing the furnaces and other apparatus by which these processes can be successfully conducted.

Carborundum.—Carborundum is not a natural product, but is produced in the electric furnace by the chemical reaction between coke and silica sand, at a temperature of 1,840° C., forming silicon carbide. This substance will stand a temperature up to 2,240° C., and is not then melted, but if heated beyond this temperature it is decomposed into its elements, viz.—silicon and graphite. Carborundum is a crystalline substance, and is a good conductor of heat, being about nine times as rapid in conductivity as firebrick, with the advantage of being practically constant as to expansion and contraction by heat and cold, while it resists almost all reagents except basic ones at high temperatures.

The useful substances termed "carborundum refractories"—composed principally of silicon carbide—vary only as to the different bonding material used in their manufacture.

There are four types of carborundum refractories manufactured by the Carborundum Company of Perth Amboy, N.J., U.S.A., to whom the author is indebted for the particulars given.

Type 1. Bonded carborundum shapes (carbofrax).
,, 2. Re-crystallised carborundum shapes (refrax and silfrax).
,, 3. Carborundum cement.
,, 4. Carborundum fire-sand mixes.

The first-mentioned type is the best known, and is composed of crystals of silicon carbide, bound together with a small amount of "highly refractory bonding material," and made in three varieties, named :—Carbofrax "A," Carbofrax "B," and Carbofrax "C." These differ only very slightly, and are moulded into suitable shapes for use in furnace linings, while any special shape can be made as required for any refractory purpose. As carbofrax contains only a very small quantity of bonding matter, it possesses all the qualities of carborundum.

PROPERTIES OF BONDED CARBORUNDUM ("CARBOFRAX").

	A.	B.*	C.*
Percentage carborundum,	above 98%	above 90%	above 94%
Apparent density, . .	2·45	2·52	2·60
Fusion point, . . .	above 1800° C.	above 1750° C.	above 1800° C.
Specific heat (23° C.), .	0·18	0·18	0·18
Specific electrical resistance (25° C.), . . .	..	100,000 ohms/cm³.	125 megohms/cm³.
Specific electrical resistance (1500° C.), . . .	..	750 ,,	8590 ohms/cm³.
Spalling relative to best fireclay, . . .	One-eighth.	One-half.	One-thirtieth.
Abrasion, cold, relative to best fireclay, . .	One-twelfth.	One-twelfth.	One-twenty-fifth.
Abrasion, hot, relative to best fireclay, . .	One-tenth.	One-fourth.	One-tenth.

The material is now used extensively in both gas and oil-fired furnaces, on account of its resistance to corrosive gases and high temperature.

It is stated to be very satisfactory in furnaces of the muffle and semi-muffle types, giving good thermal conductivity with uniform heating. In the pottery trade good saggars are made of this substance, replacing fireclay saggars, with greater thermal efficiency.

It is also stated that when firebox linings are made of this substance for chain grate stokers, clinkers are easily removed from it without damaging the material.

"Refrax" and "Silfrax."—By means of a re-crystallisation process, two products are produced, composed wholly of carborundum, and held together by the interlocking of the crystals. The difference between the two products is principally in the size of the crystals forming the mass of silicon carbide. "Silfrax" is composed of extremely fine carborundum powder, and "refrax" of coarser particles.

"Silfrax" is manufactured into small pieces principally, such as muffles, where walls do not exceed three-quarters of an inch in thickness, also for the sheaths of pyrometer tubes. "Refrax" is made up into larger shapes. These

* Carbofrax "B" and Carbofrax "C" are not now manufactured, being superseded by Carbofrax "A" in all applications.

substances require no bonding material and hence no changes in qualities recur. They are composed entirely of silicon carbide crystals.

PROPERTIES OF "REFRAX."

Composition,	98·99 per cent. silicon carbide.
Decomposition temperature,	2240° C.
Apparent density of brick,	2·30.
Porosity,	28 per cent.
Specific gravity,	3·18.
Tensile strength,	1,000-2,000 lbs. per square inch.
Crushing strength,	12,500 lbs. per square inch.
Specific heat, 23° C.,	0·162.
Specific electrical resistance at 20° C.,	0·107 ohm per cm.^{3}
" " " at 1,500° C.,	1·6 ohms per cm.^{3}

Spalling equal to best fireclay.
Abrasion, cold, $\frac{1}{2\frac{1}{5}}$ best fireclay brick.
Abrasion, hot, $\frac{1}{2}$ best fireclay brick.

"Refrax" is of great use in furnace linings where maximum strength is required along with the greatest refractability without softening or distortion of form. Unfortunately, however, the production of "refrax" is very difficult. The makers therefore recommend its use in furnaces for positions exposed to the most severe conditions, where nothing else will stand, as only simple shapes can be manufactured of this material.

Carborundum Cements.—For the purpose of fixing blocks or bricks of carborundum, and for patching and repairing linings of furnaces, a series of cements are made, composed principally of carborundum. Some of these cements cannot be vitrified unless exposed to the highest temperatures, and are therefore useless in furnaces exposed to a moderate temperature; other classes of cement are made for these lower temperatures, and would be unsatisfactory for the higher temperature work. It is therefore convenient in that for all classes of work a special cement is made for the temperature required in the furnace. The following table contains some of the properties of these different classes of cements:—

Cement.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.
Vitrification apparent at	1350° C.	1350° C.	1300° C.	± 800° C.	± 800° C.	± 800° C.
Fusion temperature (Cone method),	1800° C.	1800° C.	1725° C.	1700° C.	1550° C.	1800° C.
Volume contraction on air-drying 100° C.,	7·17%	6·8%	4·4%	5·4%	16·4%	11·2%
Tensile strength in lbs. per sq. in. after kiln burning at 1370° C.,	1780	1585	1665	1200	1470	1620
Apparent density after kiln burning at 1370° C.,	2·36	2·41	2·03	1·99	1·99	2·09
Additional volume change on kiln firing (1370° C.),	+ 2·6%	+ 2·3%	+ 2·0%	+ 5·4%	..	+ 8·7%

Carborundum Firesand and Mixes.—These substances are manufactured for the purpose of making linings for furnaces by the process of "ramming up."

They are composed principally of silicon carbide, together with possibly a small quantity of silicon oxycarbides formed by the partial reduction of silica in the reaction produced by the high temperature prevailing in the electrical furnace during the production of the carborundum.

This material, although inferior as a furnace lining, in the property of withstanding very elevated temperatures, is yet superior to most of the types of fire-resisting materials used for furnace linings. When using this "firesand," it is necessary to mix with it some binding material, and mixtures are prepared for use, or the fine sand can be procured for various purposes in several degrees of fineness, without bonding material, so that any desired bonding material may be added to suit the purpose required.

In prepared mixes placed upon the market, the different sizes of particles have been carefully standardised, because the size of the grain has an important bearing upon the strength and refractability of the firesand when burned *in situ*.

Bonding materials consist principally of the most refractory fireclays, combined with a small amount of sodium silicate, but it is perhaps needless to say that this latter material should be used with great caution, owing to its fluxibility with fireclay and other materials that may come into contact with it in the furnace. It is stated by the Carborundum Company that carborundum refractories have been very successfully applied in the following types of furnaces and kilns :—

1. Heat treating furnaces.
2. Forge furnaces.
3. Boiler furnace side walls, arches, etc.
4. Roofs for open-hearth furnaces.
5. All types of oil burning furnaces and constructions subject to erosion by oil flames.
6. Roofs of electric steel furnaces.
7. Electric brass melting furnace.
8. High temperature pottery kilns.
9. Tunnel kiln construction.
10. Muffles of all types.
11. By-product coke ovens.
12. Rotary kilns.
13. Refractory constructions subjected to mechanical or flame abrasion.
14. Refractory constructions requiring mechanical strength at high temperatures.
15. For installations where the refractory is required to transmit heat.

The Manufacture of Firebricks.—All bricks, lumps, or retorts made of clay have to be fired in order to consolidate them previously to their being built into the furnace or setting intended for them.

The clay of which these are made, however, requires to undergo certain processes before it can be made into the various shapes and forms required.

Fireclay is generally found in a state of semi-rock—that is, it is hard and dry—and is often mined along with the coal under which it lies, also in open excavations where it is found near the surface ; from the mine it is brought to the crushing mill, where it is ground to a powder. That which will not pass through a sieve of a certain mesh is thrown back into the grinding mill. After grinding it is mixed with a certain quantity of water, and then kneaded thoroughly into a very stiff paste or dough. This paste or dough of

Comparative Physical Properties of Refractory Materials.

	Apparent Density.	Specific Heat.	Thermal Conductivity in Gram-Calories per Second per Cm. Cube per Degree C.			Compressive Strength in Lbs. per Sq. In.	Spalling Loss, ten heats to 1350° C. with sudden air cooling after each heat.[3]	Abrasion (inches) by Carborundum Wheel 12" Grit 16 Bond G – 5 grade 1·1560 surface ft. per min., brick end held to wheel at 25 lb. pressure 5 min. period.[4]		Electrical Resistance in Ohms per Cm.[3] (except where megohms are indicated).[5]			
			Average K at 100° C.	Average K at 1000° C.	Mean Value K approximate 0° to 1000° C.			Cold.	Hot.	20° C.	800° C.	1,200° C.	1,500° C.
							Per Cent.						
Refrax,	2·30	0·16*	..	..	0·024 *	12,500*	12	0·01	0·07	107 ohms.	6·5 ohms.	2·45 ohms.	1·62 ohms.
Carbofrax A,	2·45	0·18*	..	..	0·024 *	..	6	0·02	0·01	..	..	..	..
Carbofrax B,	2·52	0·18*	..	..	0·024 *	14,700*	8	0·02	0·03	107,200	12,550	4,160	745
Carbofrax C,	2·60	0·18*	..	..	0·024 *	..	0·3	0·01	0·01	<127 meg.	835,000	29,500	8,590
Silica,	1·66	0·19*	0·0022[1]	0·00426[1]	0·00313[1]	2,300*	100	0·17	..	<125 meg.	2·38 meg.	62,000	8,420
Fireclay—													
1st quality,	1·78	0·19	0·00169[1]	0·00339[1]	0·00269[1]	1,050*	9	0·26	0·11	<137 meg.	57,600	4,160	890
2nd quality,	2·04	0·19	..	..	..	..	65	0·25	0·09	..	..	..	..
Chrome,	2·83	0·17	..	..	0·0034[2]	3,900*	100	0·07	0·27	48 meg.	803	63	41
Zirconia (natural),	3·3	..	..	..	..	..	53	0·02	0·06	<134 meg.	558,000	7,710	412
Magnesia,	2·27	0·22	..	0·0135[1]	0·0135[1]	4,800*	100	0·05	12·5	<137 meg.	5 meg.	193,000	2,500
Bauxite,	1·91	..	..	..	0·0033[2]	..	43	0·02	0·04	<133 meg.	109,000	6,100	1,100
Quartzite,	..	..	0·00201[1]	0·00339[1]	0·00268[1]	..	..	..	..	..	..	..	..

* Best available values, subject to revision.

[1] Dudley, *Trans. Am. Electrochem. Soc.*, xxvii., p. 327, 1915.

[2] Wologdine, *Electrochem. Met. Ind.*, 7,382, 1909.

[3] Hartman and Hougen, *Trans. Am. Electrochem. Soc.*, vol. xxxvii. (1920).

[4] Hartman and Kobler, *Trans. Am. Electrochem. Soc.*, vol. xxxvii. (1920).

[5] Hartman, Sullivan and Allen, *Trans. Am. Electrochem. Soc. Ind.*, vol. xxxviii. (1920).

the consistency of putty is taken to the moulding bench, where the bricks and other articles are generally formed by hand. The raw clay is sometimes used to form bricks, but for the best quality, to stand variations of temperature, the clay is mixed with a certain quantity of old brick ground up to the consistency of coarse sand. This mixture gives a porosity to the articles formed, and prevents undue shrinkage or cracking when the article is built into the furnace or setting.

Homogeneity in the mass of the clay forming the brick, retort, or other article is the object aimed at in the formation of these refractories, and the difficulty of attaining this has been a great problem in the manufacture of retorts or crucibles, and the larger types of fireclay blocks. In the manufacture of zinc retorts —that is, the retorts used in the distillation of zinc from its oxide or carbonate—as well as the pots used in the manufacture of glass and gas retorts, have to be built up piece by piece with the clay in the size of walnuts, and worked into the object under construction with the workman's fingers.

Hydraulic machinery has been used for the purpose of forming these articles, which are pressed into a mould in one solid mass. The interior or hollow part of the retort having been bored out by a machine, the mould is then opened, and the retort taken out. The purpose of using hydraulic pressure is for the more perfect forming of the articles, whether bricks, retorts, or other articles, with the minimum amount of moisture, in order to obviate the inevitable contraction and splitting consequent on desiccation. This process has proved to be a great success, not only in the formation of larger retorts of better shape, but in the process of drying, by a large saving in time and without the danger of deformation in the process, as often happened in the old process, where the water as it evaporated from one part of the article condensed and ran down into another part, softening it unduly, and by the pressure of its own weight deforming it.

The manufacture of bricks of the usual size of 9 inches long by 4½ inches broad, and 2 to 2½ and 3 inches thick, does not present such a problem. However, the drying takes time and is also expensive, and where possible the bricks are made by what is termed the semi-dry process above referred to; they can then be guaranteed to have a better and more uniform shape than those formed by the wet process, owing to the fact that there is a difference sometimes of half an inch in the length of bricks formed by the latter process, due partly to the stacking in the furnace (their position when stacked, and subjection to steam condensing on them from the other bricks situated at a hotter part of the kiln), and to the quantity of water used in their formation.

The clay for the formation of the bricks having been tempered to the proper consistency is placed on the moulders' table, a piece of the requisite size is cut off and thrown into the mould with some force, so that the clay may find its way into the corners. The mould is generally made of bronze, with a false bottom, in which the imprint is placed, and is covered with a piece of felt. The workman, after pressing the clay carefully, so that no vacant spaces are left in the mould, scrapes off the superfluous clay from the top of the mould, and lifts the mould. The workman's assistant takes the brick thus formed away. Generally a workman and his boy assistant can make about 2,000 bricks by hand per day. Common bricks are now generally made by machinery, of which there are several types, but machinery has not been so universally applied to the manufacture of firebricks.

When the bricks have been formed or moulded, they are carried away to the drying floors, heated by flues underneath either with waste heat from the kilns,

by steam, or by direct firing. This drying process is most important, and has to be carefully done; undue hastening of the process must be avoided; it would distort the shape of the bricks or crack them. The floor or plates on which the bricks or articles are placed must be smooth and level for the same reason.

When the goods are sufficiently desiccated, they are carefully collected on wheelbarrows and taken to the burning kilns, where they are stacked. This part of the process is also of great importance, since the bricks or other articles, being placed one over the other, or stacked, those at the bottom have to bear the superincumbent weight of all those above, and on green bricks this is very considerable. Stacking therefore has to be performed intelligently, so that spaces are left between each brick, with the right amount of clearance for the purpose of allowing the heat or flame to penetrate the entire mass, so that a very uniform heating may be secured, with the object of getting as even a temperature as possible in all parts of the kiln.

The kiln for burning firebricks is generally constructed on the lines of a pottery kiln. Some are constructed in a circular form, and others are formed as in fig. 13, rectangular in plan, with outside walls of brick along two sides, the

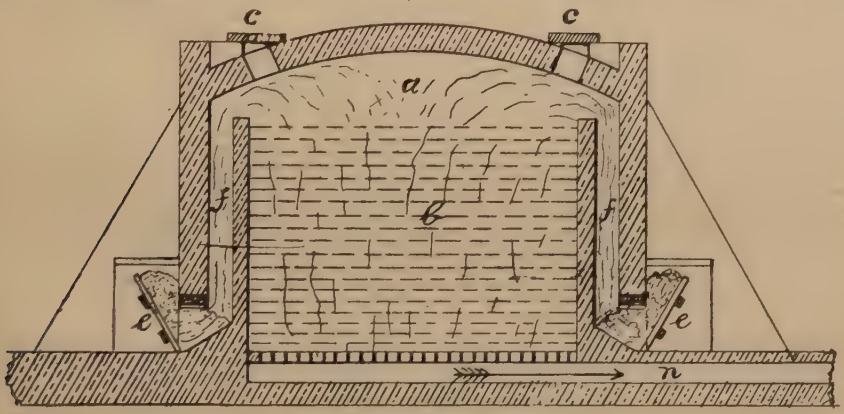


Fig. 13.—Brick Kiln (Section).

ends having a doorway large enough to admit the workmen with their wheelbarrows of bricks. Referring to fig. 13, it will be seen that the kiln is built with a roof of brickwork, through which are a series of sight holes *c*, *c*, covered with fireclay tiles, which can be adjusted. The fireplaces are formed along each side, as shown in section at *e*, generally with sloping bars of steel, the coal being piled up on the fire bars, completely blocking the entrance of cold air over the fire. The products of combustion find their way up the internal flues *f*, *f*, into the upper portion of the kiln *a*, whence the heat and flame descend through the stack of bricks *b* to the floor, which is formed with flues with openings into it. The heated air and spent products of combustion find their way ultimately to the chimney by the flue *n*. After the kiln has been charged with the desiccated bricks they are anything but completely dry, and great caution has to be exercised in starting the fires, so that the moisture is drawn off gradually. The fires are therefore very carefully maintained and gradually augmented, at the same time the covers *c* are adjusted to allow the superfluous steam to escape, in order to prevent too much moisture from descending into the colder region of the kiln, where it would condense on the green bricks, and damage

them. When the firing has been successfully carried on beyond the stage of thorough desiccation, the draught of the chimney stack draws the heat downwards through the stack of bricks, until the whole kiln has attained a temperature sufficient for the purpose required, at which it is maintained for a few days, after which the kiln is completely closed up, and allowed to cool.

In the burning of red clay bricks, kilns of a similar construction are used, with the same precautions, and when the kiln has attained its proper heat for firing the goods the workman takes out a sample with a pair of tongs through the opening *c*, and at the exact period when the correct amount of colour has been developed—that is, when the oxidation of the iron in the bricks is requisite to form the desired colour—the kiln is closed up, and no air is allowed to enter, so that the colour may not be changed, and the kiln is left to cool.

In this class of kiln round coal is generally used, as the small slack makes the fire too close, the air not being able to penetrate sufficiently ; this class of coal generally contains a larger quantity of ash and is therefore objectionable on these grounds, as necessitating the frequent cleaning of the fire grate, which is a rather risky business, at certain times, by reason of the inrush of cold air.

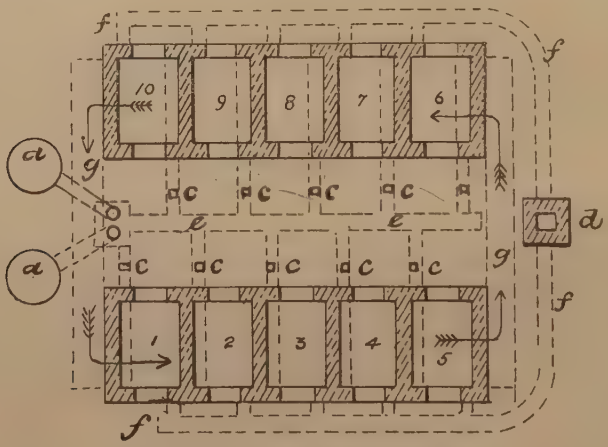


Fig. 14.—Plan of Dunnachie Patent Kiln.

Continuous kilns have been constructed for the purpose of burning bricks, and gas firing has been very successfully applied for this purpose.

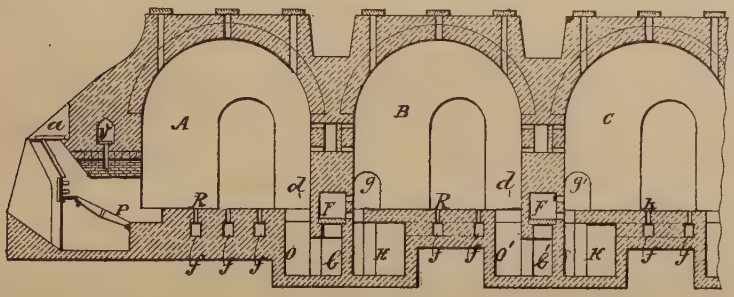
The gas-fired kiln of James Dunnachie, B.P., 17,573, A.D. 1890, is one of the best. A sectional plan of this kiln is shown in fig. 14. The gas is supplied by means of two gas producers *a*, *a*, from which the gas is conveyed by a pipe *e*, which has a series of branch pipes to each separate compartment in the kiln. The kiln shown in the drawing has 10 compartments. Any number of these compartments may, however, be used. When the bricks or goods in kiln compartment No. 1 are fired, the hot products of combustion of the gas are carried through Nos. 2, 3, 4, etc., before reaching the chimney stack ; this is accomplished by means of dampers provided in the branch flues to the chimney flue, so that when a series of compartments are in successive progression, in the process of being emptied, refilled, steaming, heating up, and firing, all these are progressing consecutively at the same time. The air for combustion is pre-heated by being drawn through the series of bricks in the compartments

which have been already fired, and are cooling off. This heated air meets the gas issuing through a series of port holes in the floor *R* (figs. 15 and 15a), and combustion takes place; the products of this combustion issue from the chamber *A*, and pass into the chamber *B*, through horizontal openings in the division wall between these chambers. Figs. 15 and 15a show another method of firing by means of the fireplaces shown at *P*, *P*. These are used in any case for the purpose of lighting up this kiln. In the kiln shown in fig. 14 no fireplaces are used.

The gas and air are under complete control, the former by means of gas valves *c* (fig. 14), and the latter by means of dampers on the flues.

By this means of continuous gas firing a more uniform temperature can be

Fig. 15.—Sectional Elevation of Dunnachie Patent Kiln.



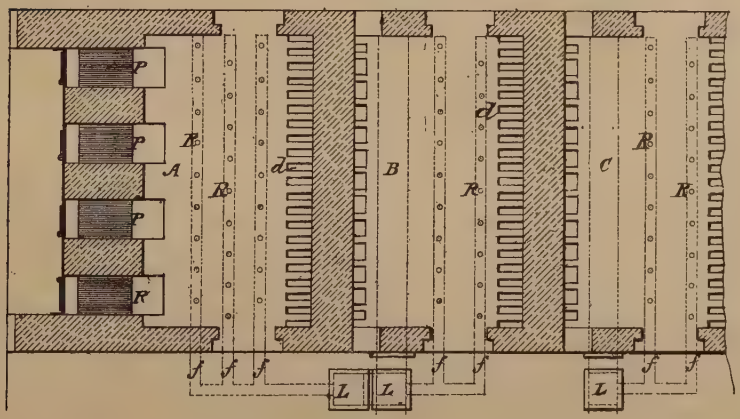


Fig. 15a.—Plan of Dunnachie Patent Kiln.

acquired and maintained during the progress of the firing, with the advantage of a large saving in fuel by using the waste heat from the cooling-off chamber in pre-heating the air for combustion.

Other advantages of gas firing are that it is very much cleaner, no clinkers are formed, no ashes require to be removed, there are no fires to be attended to in the kiln itself, and there is therefore no deposit of dust on the goods. The kiln, by using pre-heated air, will be heated to a higher temperature than by the ordinary means of firing with direct fire grates, so that the bricks can thereby attain the maximum temperature necessary to insure their complete contraction. This is a point of great necessity in the manufacture of

firebricks, for they should be subjected in the kiln to the highest temperature that they will stand without damage, so that when they are built into position in the furnace they will neither shrink nor crack.

Referring to figs. 15 and 15a which show a plan and section, the procedure in working this kiln is as follows: supposing that a kiln of bricks has just been fired in compartment *A*, and air is being admitted to this chamber to cool the bricks, this air by passing through the bricks is heated and makes its exit through the opening in the lower part of the kiln at *d*; from there it passes into the flue *o* and *b*, and through the passage *F* by small openings into the adjoining chamber *B*, where it meets the gas issuing through the ports *g*. The products of combustion then traverse the stack of bricks in chamber *B*. This is repeated in chamber *C* and so on, as each chamber is furnished with a similar set of flues and gas ports. When a chamber is being emptied it is shut off by means of dampers on the flues and exit to chimney. The flues indicated in fig. 14 by dotted lines have above them a series of small openings through which gas can be supplied for the purpose of a preliminary heating or "steaming" of the bricks, as shown at *R* (figs. 15 and 15a). In the working of such a kiln by means of gas made in a producer as indicated at *a* (fig. 14), the process is a continuous one, and by thus applying the principle of regeneration, by pre-heating the air for the combustion of the gas and at the same time cooling off the bricks in other chambers, a vast economy is secured in the costs of fuel and labour on the one hand, and on the other the advantage of securing a very high temperature for the thorough firing of the bricks and other goods in the kilns. This system has been in successful operation for upwards of 30 years at the works of the Glenboig Fireclay Co., near Glasgow.

CHAPTER III.

PREPARATION OF THE COAL.

The preparation of the charge of coal for coke ovens requires a certain amount of care and forethought if a first class metallurgical coke is the chief object of the process of carbonisation.

If the manufacture of a high class coke for foundry and blast-furnace purposes is proposed, it is absolutely necessary that very careful attention be paid to the quality of the coal employed, to its purity or freedom from inorganic materials, such as silica, iron, sulphur, phosphorus, or any matter that would deteriorate the quality of the iron manufactured by it, or would tend to flux it into the slag. These deleterious materials are often very abundant in coal, and as it is the chief agent in reducing iron from the ore, it stands to reason that the coal should be clean, and should also possess the coking qualities necessary to form a solid, hard coke capable of standing well before the blast from the tuyeres, and bearing the burden of the charge without cracking in the furnace.

There are few coals that will answer to all of these demands without some treatment, the great majority are defective in one or more of the absolute essentials, for example—some coals will have perfect coking qualities and form a perfectly sound, hard, and durable coke, will also on carbonisation give a large quantity of highly valuable by-products, such as tar, ammonia and benzol, but they may be so saturated with sulphur or phosphorus as to make the coke made from them worthless for iron smelting or other metallurgical purpose. Other coals may more or less lack the coking qualities, but may be perfectly clean and free from any of the deleterious ingredients enumerated above; while still others may have good coking qualities but have considerable quantities of silica, fireclay, slate, etc., adhering to them, especially when mined from thin seams of coal. The problem then is how to get the best coke from these coals in sufficient quantity to supply all the demands of the market, seeing that the amount of coal naturally qualified for the purpose is extremely limited. The problem is one that has received a considerable amount of attention and thought from very able and skilful engineers, and there has been developed through many years of experiment and trial, very efficient means of producing from coals that would be unfit to form metallurgical coke *per se*, an article equal in all respects to that made from the typical, ideal coking coal. These processes now in use are classified according to the various purposes required. The removal of inorganic matter termed "ash" (which means mechanically mixed rock), silica, slate, etc., from the coal, is performed by means of picking by hand on a travelling belt or conveyer, screening out the larger pieces on screens, crushing the coal that is adhering to pieces of rock, and washing and jigging it with mechanical apparatus. These processes are really wonderful in their operation, and in the perfection of separation that can be effected, giving a product fit for the coke oven and at the same time recovering a large amount

of coal that was formerly thrown away on the waste heap. As stated above, a certain portion of this work has still to be done by manual labour—that is, picking out the pieces of rock, etc., by the workmen from the coal as it slowly passes on the travelling belt or conveyer.

This separation cannot be effected by mechanical means when the pieces of rock, etc., are in large pieces because most of the mechanical separation is done by means of hydraulic machinery, and depends upon the difference in specific gravity of the coal and the material mixed with it, and therefore only material that is small enough to be acted upon by water at a reasonable pressure can be worked, the object being to separate minerals in comparatively fine division, quickly, and without much expenditure of power or use of complicated machinery.

Minerals mechanically mixed with the coals, when crushed, can be very easily separated by these means, but when substances such as sulphur or phosphorus have to be dealt with the case is extremely difficult, if not practically hopeless if the quantities present are excessive. The only way of overcoming this difficulty is by a judicious mixture with clean coal possessing less coking qualities perhaps than that containing the sulphur or phosphorus. But coal that is charged with either sulphur or phosphorus should be avoided for the manufacture of metallurgical coke ; this class of coal can be economically used for other purposes and such being the case it would be a mistake to use it or even attempt to clean it.

There are some erroneous ideas prevalent among some who have little knowledge of coke that it is possible to clean coal or coke from sulphur, and numerous attempts have been made, which have ended in failure ; it was proposed to clean coke while yet in the coke oven, red-hot, by passing a current of steam through it, because by this means sulphuretted hydrogen was given off, but it was found that while producing sulphuretted hydrogen, a large amount of carbon monoxide was also produced at the expense of the coke in the charge. Moreover, the reaction between the steam and the incandescent coke is exothermic, the amount of fuel required therefore to make up the thermal loss, together with the loss of weight of coke would make the process uneconomical ; and further, all the sulphur cannot be eliminated by this means. When steam is blown through an incandescent charge of coke in a coke oven or retort, the coke being in large masses, the steam only passes through the cracks or passages between these masses as being the path of least resistance ; therefore the outside of the pieces of coke only would be acted upon, and this only in the lower parts of the charge, near where the steam enters, as long as the heat is kept up ; but judging by the action of steam in the water gas process the coke would be rapidly chilled in spite of all the outward application of heat to keep up the reaction, so that very quickly the reaction would stop.

The difficulty with the elimination of sulphur and phosphorus is that it is generally disseminated throughout the mass of the coal and is to be found enclosed inside the walls of the cell structure of the coke.

A good deal of sulphur is given off with the gases evolved during the process of carbonisation, but this obtains more in the manufacture of gas in gas works than in coke ovens, because the gas companies' object is the manufacture of gas, the coke produced being simply a by-product, and their choice of coal rests upon the largest quantity of gas of the requisite quality which can be produced from it. On the other hand, the manufacture of gas in the coke oven is a secondary matter, the coke being the special object of manufacture. Coal, therefore, containing these deleterious matters would not be used.

The sulphur in coal is now being extracted from the gases derived from the carbonisation of coal, where sulphuric acid plants have been erected, along with the manufacture of ammonia. By this means economies are effected by picking out and extracting from the coal everything for which a use can be found; by-products are being studied by chemists and engineers more seriously now than was the practice in the past. There is an old saying, "take care of the pence and the pounds will take care of themselves," which is becoming practically applicable in all departments of applied science, and in none more so than in the carbonisation of coal and the recovery of its by-products.

When one looks round, and sees the amount of useful things produced from by-products which a few years ago were allowed to go to waste—one is astounded. Consider the value that is now obtained from the chemicals derived from tar, and the gases evolved during the carbonisation of coal.

To make a perfect metallurgical coke, therefore, coal that is clean, and free from any materials deleterious to the purpose for which the coke is to be used, must be obtained.

Nearly all the coal now made into metallurgical coke is subjected to one or more of the processes now to be described, in order to prepare and purify it.

The coal as it comes from the pit is screened and sized, by which means all the smalls fall through, and leave the lumps on the screen. Generally the screenings go to the coke oven, as all the coal destined for the manufacture of coke is put into the oven in the state of fine slack. The large coal is generally used for other purposes, unless the demand for coke is large and the amount of smalls coming through the screens is not sufficient. Elaborate screening of the coal for coke making is not required unless there is a quantity of small coal mixed with the round coal that requires to be separated on the screens for washing. After the coal has been sized and screened it is conveyed to the coal crushers or disintegrators, where it is reduced to powder.

In most collieries, since a great deal of the best coal in thick seams has become worked out, recourse is had to that in the thinner seams, and in these circumstances a quantity of the roof and floor of the seam has to be cut away to provide working room for the miners. It is therefore difficult to prevent the material of the roof and floor from being brought up with the coal both in the form of large pieces and mixed up with the fine slack, so that the coal requires therefore to undergo a washing process, to clean away the inorganic material thus mixed with it. It has been pointed out that the larger pieces of such material are picked out by hand on the travelling belt or conveyor, down to about $2\frac{1}{2}$ inches in diameter, the rest going with the coal to the crusher, and from thence to the washers. Where water is cheap and plentiful, the hydraulic process of separating the coal from the "dirt" is efficient, but as this process saturates the coal with water, when it is placed in the coke oven a quantity of time and heat is thus lost in desiccating it before coking can be commenced.

Dry processes for separating the "dirt" from the coal have been from time to time proposed and tried with little or no success, as far as can be ascertained in America; a series of screens was used, arranged so that the lighter particles of coal were separated from the gangue with or without an air blast to assist the process. One of the disadvantages of this method is the enormous amount of dust that is caused and which is so difficult to deal with. Some of it is very finely divided, and if confined would require very careful manipulation in order to prevent explosion, and at the same time it is very difficult to settle or "condense." The subsequent handling of this fine dry powder renders the dry process of separation very difficult and dangerous. Whether it will ever be made

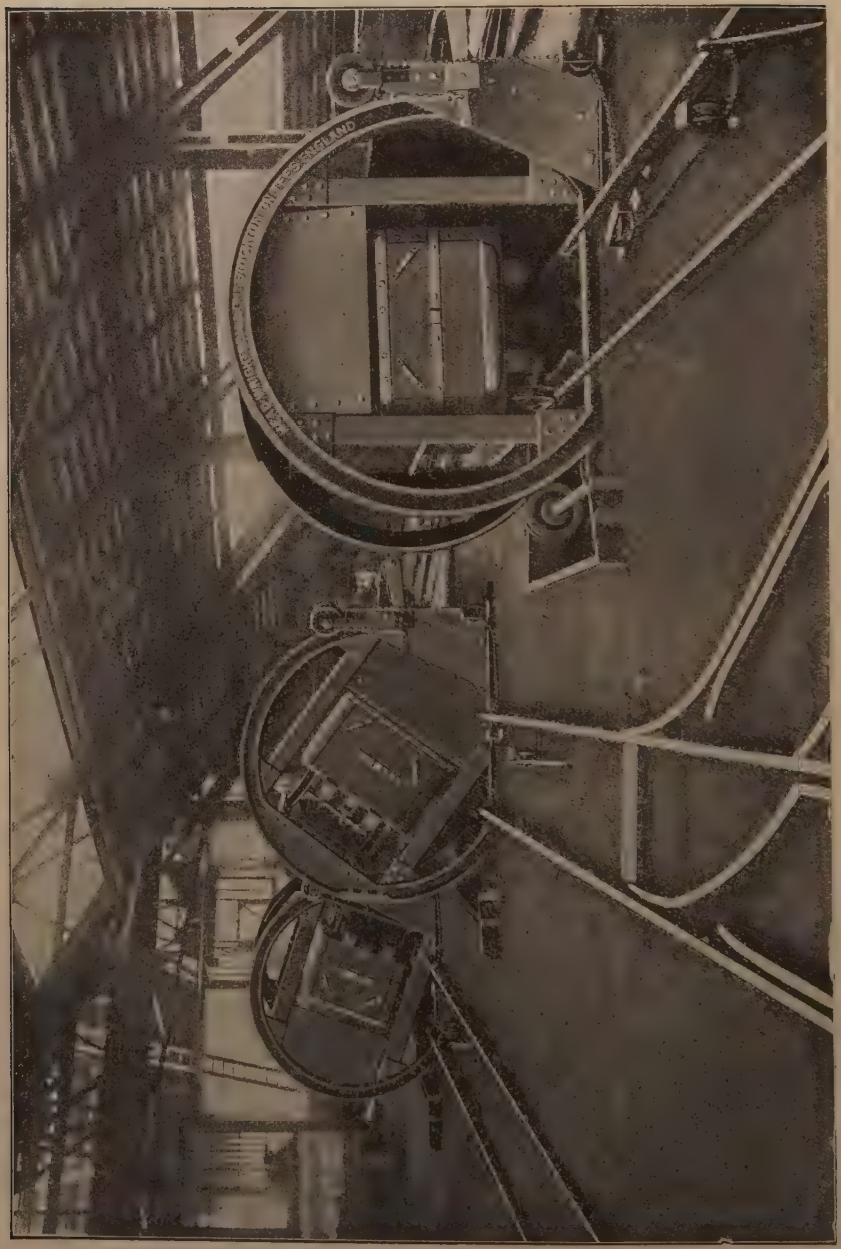


Fig. 16.—Coal Washing Plant, View of Tippler.

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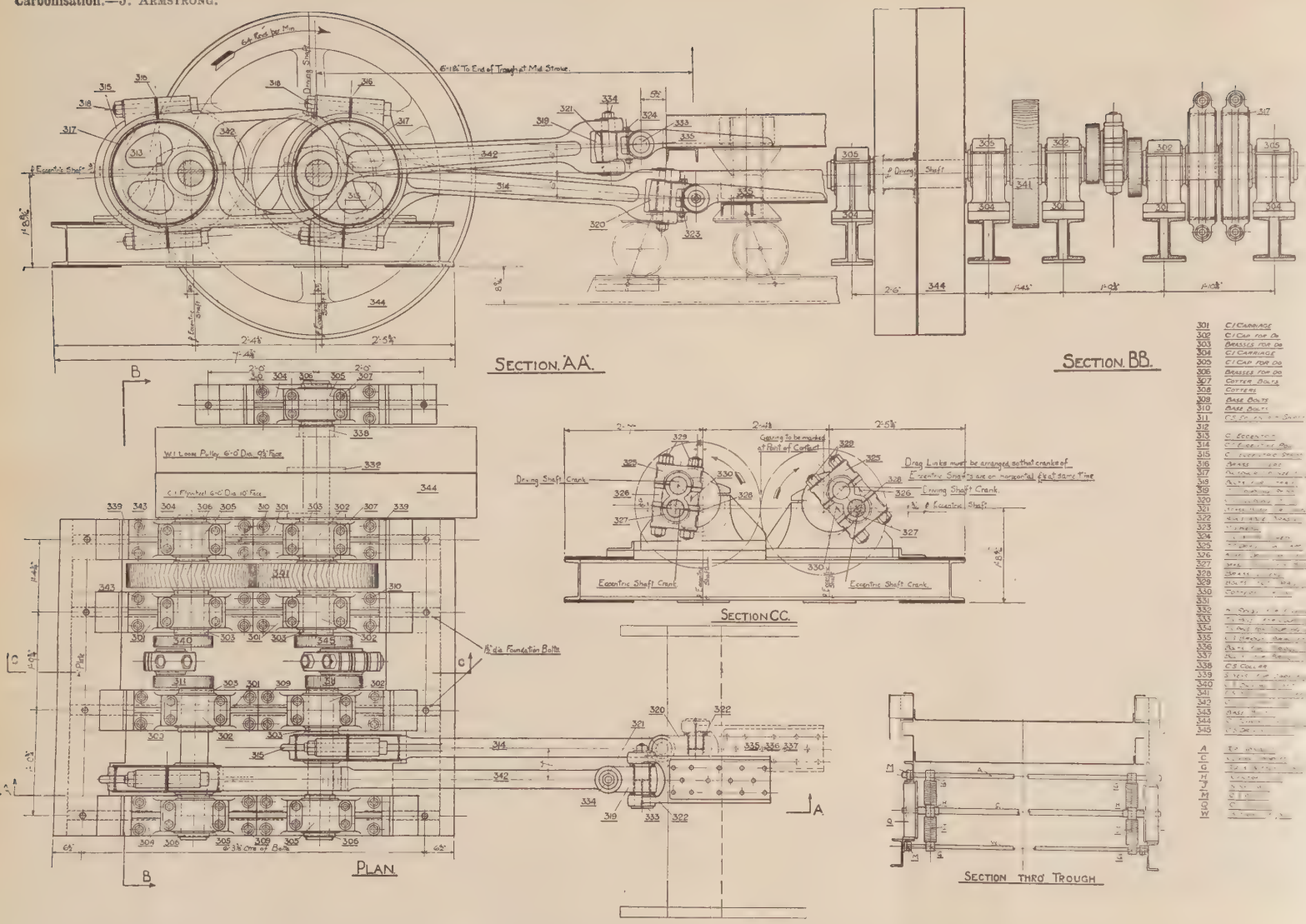

301	C/I Carriage
302	C/I Cap for Do
303	Brasses for Do
304	C/I Carriage
305	C/I Cap for Do
306	Brasses for Do
307	Cotter Bolts
308	Cotters
309	Base Bolts
310	Base Bolts
311	C.S. for [illegible]
312	
313	C. Eccentric
314	C. Eccentric Do.
315	C. Eccentric Shaft
316	Brakes [illegible]
317	[illegible]
318	[illegible]
319	[illegible]
320	[illegible]
321	[illegible]
322	[illegible]
323	[illegible]
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326	[illegible]
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330	[illegible]
331	[illegible]
332	[illegible]
333	[illegible]
334	[illegible]
335	[illegible]
336	[illegible]
337	[illegible]
338	C.S. Coupling
339	[illegible]
340	[illegible]
341	[illegible]
342	[illegible]
343	[illegible]
344	[illegible]
345	[illegible]
A	[illegible]
C	[illegible]
G	[illegible]
H	[illegible]
M	[illegible]
O	[illegible]
W	[illegible]

Fig. 17.—Plan of "Marcus" Conveyer.

Plan of Balanced "Marcus" Propulsion Gear for driving where Screens or Conveyers are placed one above another for one behind the other, and where it is intended to propel the material in both in the same direction.

economically practicable in the future is very problematical, and it would only be applicable to regions where water is scarce.

At the present time, in Great Britain, very little coal is now coked that has not been washed, with its disadvantage of containing so much moisture; it seems to be the only feasible method of dealing with coal, especially in a state of high comminution; it prevents dusting, and by means of settling tanks most of the water can be drained away if time is no object; otherwise a system of filter pressing would be useful in pressing out the surplus water, where a good recovery of coal could be made and the water used over again.

The coal is generally delivered from the mine in close proximity to the coking ovens, in tubs, which are emptied by means of a tippler, shown in fig. 16. From the tipplers the coal is thrown upon a screen which sizes it; all that passes through the screen is taken direct by an elevator to the washing plant. The larger pieces that pass over the screen are directed to the crushing plant and from this the crushed coal is tipped into the same washer and it is mixed with the other small screenings. From the washing machinery it is put through a drying process at some collieries, before it is reduced in the disintegrator to the fine state of division necessary for coking.

In some of the later methods of mechanical separation, the conveying, picking and screening are all done at one operation, as will be gathered from the illustration (fig. 17), which represents the details of a set of balanced Marcus Conveyers by Messrs Head, Wrightson & Co. The coal, after descending from the tipplers by the shoots, is received on the conveyer shown in fig. 18, where it is picked by hand and, as it passes along the conveyer, by a peculiar shaking motion the coal is screened, the small falling through the conveyer-screen upon another conveyer working underneath and at right angles to the conveyer above it. The screens are placed directly over the lower conveyer. The under conveyer carries the small coal direct to the washers, and the upper conveyer carries the larger pieces to the crushers, and ultimately, as above stated, the coal is conveyed to the washer. The mechanical handling of coal, from the time it leaves the pit until it enters the coke oven, is now practically automatic, and the number of men formerly employed has been reduced considerably. By good planning and arrangement of plant a great deal of this work can now be accomplished without the expenditure of much power.

The modern system of conveyers either by means of belts, creepers, chains, worms, or other means, has saved both time and labour to a large extent. It is now quite a common thing for from 2,000 to 2,500 tons of coal to be handled per day by a squad of men and boys that can be counted on the fingers of one hand. The mechanical means of emptying the tubs or waggons that convey the coal from the pit are shown in the illustration (fig. 16), and constitute a great improvement on the former methods of handling these trucks. The tub or truck is run on the rails right into the "tipplers," where it is caught, and automatically swung round, when its contents are completely and quickly precipitated into the shoot beneath; after the tub or truck has been thus emptied, it is again automatically passed through a semi-revolution into its upright position again, released, and delivered along the rails on the other side of the tippler, to join the train of empties, while another tub or truck is being run on to the tippler to perform the same operation. The tippler and all the mechanical movements are operated by means of a lever by the workman in charge.

After passing the shoot the coal is thrown on to the conveyer or screen, in some cases the screen is separate from the conveyer, where it is sized.

The screen may be stationary and placed at an angle so that the coal may slide down it while the smalls pass through the grid, the larger pieces passing or sliding over it and the end of the screen. Whether the screen forms part of the conveyer or not, the coal after passing it is then conveyed to the washer. Several forms of conveyers are now in use for this purpose, one of these, the new Balanced "Marcus" Propulsion Gear, shown in fig. 17, is in some cases made to act as a screen, picking belt, and conveyer. It combines two mechanisms mounted on one bedplate propelling two screens or conveyers, in such a manner that the reciprocating effort exerted on one is balanced by that exerted on the other. In this way the strain on the gear and also on the supporting structure is greatly reduced.

The Balanced "Marcus" Screen sizes coal, and is used as a picking table in exactly the same way as the ordinary "Marcus." The essential difference

Fig. 18.—Picking and Screening "Marcus" Cross Conveyers.

between the two screens is that while in the latter both decks are fixed and reciprocate as one unit, in the balanced screen the upper and lower decks are separate units, one moving forward while the other moves backward, and *vice versa*. By employing the type of propulsion gear illustrated in fig. 17, the material can be made to travel in both top and bottom decks in the direction desired.

With a jigging screen the coal is thrown from a tippler on to the screen direct, by means of which the small coal passing through the jigging screen is delivered on to a belt while the large pieces are delivered on to another belt.

The jigging screen is actuated by a shaking motion that thoroughly sifts the coal as it gradually slides down the inclined sieve ; this jigging sieve is made of

steel plates in the form of a triangle, with the sieve at the bottom, a backing roller being inserted near the top to prevent too much coal being heaped on to the sieve at once ; by the action of this roller the coal is delivered in a constant and uniform stream on to the jigging sieve. Of all the improvements that have been produced in recent years in connection with banking machinery, none has done more to revolutionise the whole system than the " Marcus " conveyer and horizontal screen. The principle of the Marcus is a trough with perforated bottom or otherwise which is made to run backwards and forwards on wheels. The rate of motion is comparatively slow, working at from 60 to 80 revolutions of the driving shaft per minute. The propulsion gear is so constructed that by means of a connecting link on the cranks of the two shafts, which are out of line, a variable speed is produced ; beginning slowly at the commencement of the stroke, the trough increases in uniform acceleration up to three-quarters of the stroke, then slows down during the last quarter, reverses, and the return stroke is inversely the same as the forward, so that instead of uniform acceleration in velocity there is uniform retardation. The low speed at each end of the stroke tends to cushion the shock. The material is carried with the trough in its forward stroke, and as it increases in speed it gradually imparts sufficient impetus to the material to overcome frictional contact with the trough in its backward stroke. Many advantages in this system are not recognised at first sight, but the following will show that the features gained are of great importance. As the screen can be horizontal, or even inclined in the opposite direction, to the ordinary screen, it will be seen that the height of the whole construction can be materially reduced and quite a low building is all that is needed. The screen and picking trough are combined and at each stroke of the trough every piece of coal changes its position, so that is it impossible for shale or refuse to be covered up under pieces of coal and so escape the eye of the picker.

All small coal made during the process of picking under ordinary conditions, excepting on the bar bolt, finds its way into the large size, whereas the small made during the process of picking on the Marcus, goes through the perforations with the smaller sizes. By those who have never seen the Marcus at work, it has been objected to on the ground that it would be trying to the eyes of the picker, but it has been proved by experience to be quite the reverse.

In places where this system is used, and pickers are working side by side with ordinary picking belts, they prefer to work on the Marcus because the coal is constantly altering its position in the trough, thereby giving the pickers a better chance of discerning the shale and other gangue from the good coal. Under ordinary circumstances where it is required to make a number of different kinds of coal and to mix them again if desired, a most complicated and expensive arrangement of belts is necessary, whereas by putting a second deck into the Marcus screen, with sliding doors, the different sizes can be mixed after they have been picked, to meet the various market demands.

All the mechanism and working parts are placed at one end, and there is no wear and tear on the links, pins, drums, etc., as is often the case with ordinary belts. After a few weeks' work, the trough becomes quite bright and smooth, and the material travels along gently with very little friction. The power required to drive this type of screen is regulated somewhat by the length and size of the perforations employed in the screen; generally speaking, a 60-foot screen takes from 10 to 12 H.P., while it is possible to convey 325 tons of coal per hour and only absorb about 7 H.P. in a plain trough; the introduction of a screening trough with perforated plates retards the progress of the coal, but it

is always possible to convey on a screen much more than can be efficiently picked.

There are a great variety of screens employed for the separation of the small from the large pieces of coal; some are simply shoots, with screens in the bottoms, made of bars, set at an inclination, so that the coal will slide down without sticking or forming heaps, and at the same time will sift the small coal through the bars, while the large pieces slide over the end: the inclination generally given to this class of screen is about 1 in 2 to 1 in 1¼. Of this class, one of the best is Chambers' Patent Screen, consisting of perforated channel bars, supported upon pins which are rocked by means of levers driven by rods from eccentrics on the main driving shaft. The bars are also connected to a series of rods fixed to a rocking lever which is driven by another set of eccentrics, giving a lateral motion to the bars; every alternate bar thus rises and moves forward, carrying the coal along with it, while the alternate set of bars are making their backward movement, and *vice versa*. The bars move slightly up and down, upward in the forward movement and downward in the backward movement.

This screen will work without any inclination, but it gives better results when slightly inclined.

There are screens made with a gyratory movement, such as Beaumont's, made by the Hardy Patent Pick Co., and called the "Vibrometer." It consists of a swinging plate fixed in a frame. The plate is perforated and acts as a sieve, this plate and frame being suspended by means of wire ropes, so that it is free to move in any direction.

There are several other kinds of screens, such as jigging screens actuated by gyratory motion or by eccentrics, or by cranks, which give the screen a forward push with an upward movement, whereby the coal receives a jerk which moves it forward. But most of these forms are used for classifying coal for sale purposes, a full description of which does not come within the scope of this work.

COAL WASHING.

Theory of Coal Washing.—The washing out of the dirt from minerals, or the separation of one mineral from another is a very old practice, and is used to get metals, such as gold, lead, tin, zinc, copper, etc., from the ore. The ore or rock is first crushed and then passed into a jigging machine where the coarser material is separated. The finer material is then passed over a table called a vanner, where very fine separation is effected between minerals whose specific gravities nearly approach each other. The vanner table is flat, with a slight inclination to one side, with a stream of water flowing along it: a vibratory motion of a forward character, similar to the motion actuating some classes of conveyers, is given to the table, and by jerking the material forward by small impulses, the particles of the mineral operated upon are thus kept in motion, and separated by the water current passing over them: the lighter particles being washed sideways by the flow of the water, while the heavier particles are jerked forward by the vibratory action given to the table.

For example, in dealing with an ore containing free gold, galena, zinc blende, and silica, the separation is effected by absolute zones of the several metals and minerals in the ore, each being quite separate and distinct, so that at the edge of the table where the several streams of these minerals are travelling, separate pockets are appended, and each metal or mineral will constantly find its way into its own pocket, a perfect separation being thus maintained throughout the operation in accordance with the distinctive specific gravity. The work

of the vanner is necessarily a slow process, but in the case of the precious metals, the process is inexpensive, and other more laborious and complicated methods are avoided.

Sometimes even the vanner is incapable of separating the minerals and other means have been devised. The "Flotation process" consists briefly in the application of certain reagents such as acids or alkalis which attack the metalliferous ore and discharge gas on the surface of the particles, forming small globules; the gas being lighter than water, buoys up the particles and causes them to float, while the silica and other non-metalliferous gangue, not acted on by the reagents, sinks to the bottom. The lighter particles—that is, those which float by reason of the gas bubbles—are carried away to settling tanks and are recovered.

With regard to the separation of deleterious matter from coal, it is questionable whether the vanner or the flotation system can be applicable from any economic point of view, although it is claimed that these processes are capable of being applied. The whole problem of water separation of minerals is a question of the specific gravities of the materials comprising the matter under treatment. The separation is effected by the action of the impulse of water against the mass of mixed mineral matter and coal, whereby the coal, being the lighter, occupies the upper part of the apparatus, while the heavier mineral sinks to the bottom. Several inventions for carrying out these principles of separation have been made, each of which has its own special claim to deal with a certain class of coal, and give a certain result.

There are, however, principles which from time to time have been observed in the practical working of these machines and processes, which have now become established; that is, in the cleaning of coal, it should first be screened, then picked by hand, then crushed (for coke making), classified and washed. There are some collieries which still follow the method of washing first, then classifying, as in the Baum washers. In almost all the other washers the principles are the same, and are all dependent upon the fall to the bottom of the heavier particles through the water, by gravity. But it must be observed that this is not quite so simple a matter as it may at first appear. If all the particles of the matter of the mixture undergoing separation were of the same size the problem would be at once simplified, but they are not, on the contrary they are all of different sizes from comminuted powder up to that which first passes through the sieves; but pieces of coal and mineral gangue of different sizes may be the same weight, and balance each other in the rate of fall through the water. For instance, a piece of coal of which the specific gravity is 1·3, will descend through water in practice at the same rate as a piece of mineral of nearly twice its specific gravity, the relative size of the former to the latter being in proportion of about 3·5 to 1.

The washer, therefore, has to deal with the matter not only of different specific gravities, but of different sizes, making the problem of separation complicated. In the case of coal, a certain type of plant, or process, which may be quite successful at one colliery dealing with coal carrying a certain class of gangue, may not be at all suitable at another colliery where the gangue is of a different specific gravity. In a washer dealing with coal the rate of motion of the water upwards should be less than the speed of the gangue travelling downwards—that is, the flow of the water should be such as to allow the gangue to drop through it to the bottom, otherwise the gangue will be lifted and carried away with the good coal. Most washing machines have a pulsating action, which in some cases may be useful in shaking particles of coal free from the gangue adhering to them; some machines are quite stationary, their action

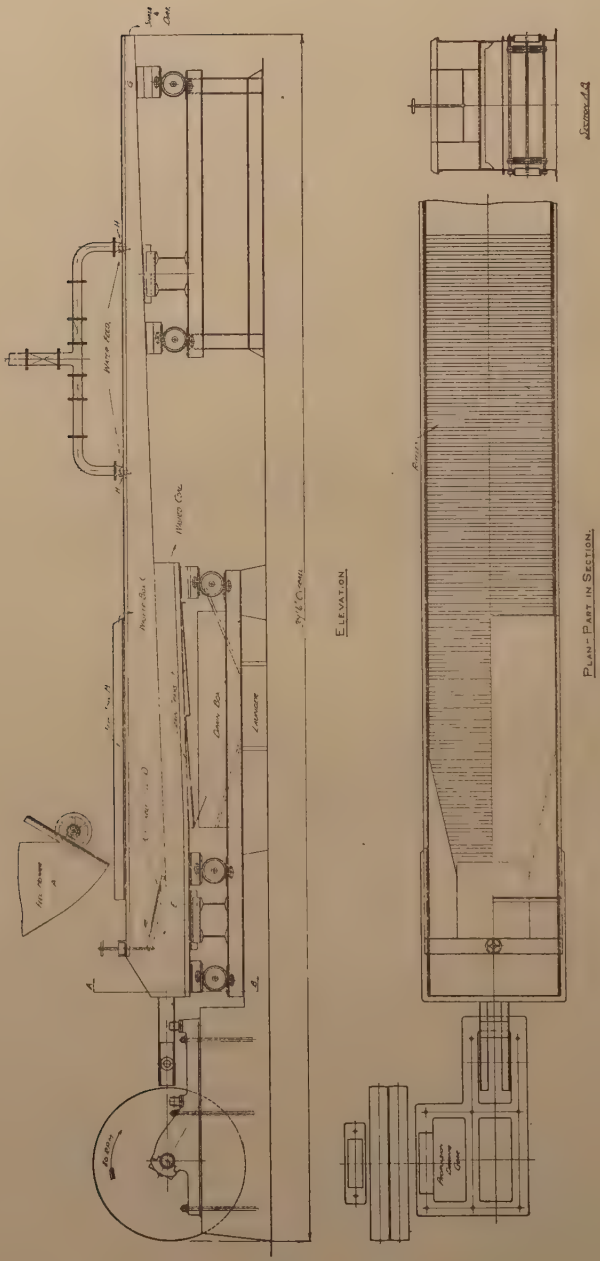


Fig. 19.—Plan and Section of "Nofa Nos" Coal Washer.

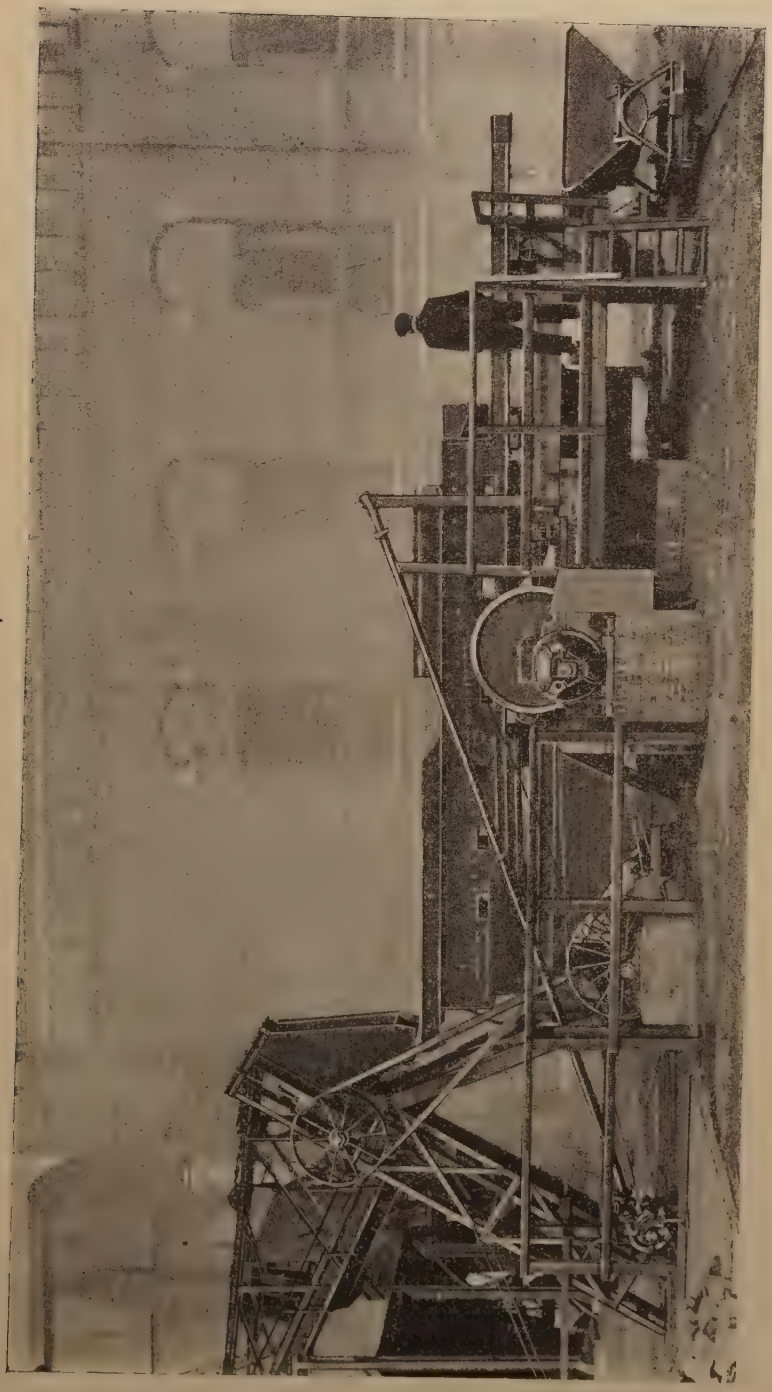


Fig. 20.—Elevation of "Nota Nos" Coal Washer.

depending upon a steady flow of water as in the Robinson washer, where the steady stream of water flowing in an upward direction floats off the particles of coal; but in this apparatus, there is a mechanical mixer or stirrer constantly moving the coal and the mineral matter in a conical shaped box.

One of the most up-to-date machines and a machine which has proved its efficiency in treating coal for coke production is the "Craig" Patent Coal washer; it is designed on the plan of the vanner, described above, for dressing ores. This washer consists of a mixing tank, formed circular on plan, filled with water, into which the coal is discharged direct from the pulverising machines; inside this tank are a set of agitators, consisting of revolving arms which constantly stir and mix up the contents of the tank, and keep the coal and the other matter mixed with it from settling to the bottom and thus becoming a solid mass, and arrangements are provided for the purpose of allowing the coal, etc., to flow from a number of shoots, each of which is directed upon a table, similar to that described above in reference to the vanner. This table is triangular shaped, and is mounted upon a carriage running on rails. The rails are placed on an inclined plane but the table itself is practically level.

The action of the table is that of a backward and forward motion, actuated by means of a cam working on a piece of metal fixed on the end of the table; the cam is worked by means of a shaft, to which it is attached, and making some 30 revolutions per minute; by the cam the table is pushed backward, but as the cam revolves and passes the end of the table the latter is brought forward with a jerk, by the action of a strong spring; this forward stroke of the table is arrested by a set of buffers, imparting to the table a set of jerks by which the coal on it is impelled forward by the water, which is the lighter material, while the heavier gangue is impelled backward by the action of the machine. The coal flowing away with the water is collected in settling tanks and the gangue is discharged by the openings at each side of the machine.

This machine is thus different from most coal washing machines, which are generally of the jig type and treat coal more especially for grading for sale, but for the treatment of highly comminuted coal there is no doubt that this is one of the best. The machines for washing coal crushed to about $\frac{1}{4}$ inch in diameter and of the jigging type, work with water only, but when coal that will pass through a sieve of $\frac{1}{4}$-inch mesh, and sieves of still smaller mesh, comes to such machines, it is necessary to employ means to arrest the small grains and prevent their escape in the overflowing water. It is therefore questionable if the Craig washer could compete with a jig machine in dealing with coal crushed to $\frac{1}{4}$ inch and over, while on the other hand it will deal better with the smaller stuff. Another machine of the first class is the "Nota Nos" Coal Washer, shown in plan and section in fig. 19, and in general elevation in fig. 20; in this the water carries away the washed coal over the adjustable sill, the coal then passing through the grid at the bottom of the sill, while the dirt and shale are carried away forward by the water and the jigging movement of the machine. In jig machines, when coal thus fine has to be dealt with, a sieve is inserted in the jig hopper, upon which a bed of feldspar is placed, broken into pieces, just large enough not to go through the sieve, so that a grip may be had upon the gangue, which becomes enclosed between the particles of feldspar. The specific gravity of feldspar is, generally, a little lower than that of the gangue, but higher than that of coal; so that the gangue is gradually worked under the feldspar, and through the sieve in the base of the hopper, while the feldspar, which acts as a sort of trap for the gangue, rests in its original position on the sieve; the coal, however, which

is lighter, is elevated above the feldspar, by the action of the water, and passes with the water into the setting tanks.

The jig machines are most efficient in dealing with coal that is not comminuted, as the fine particles of the gangue would be carried away with the coal and be mixed with it, by reason of the principles already referred to, the slower descent in water of each individual piece of material as it decreases in size or volume. When the limit is reached, that all pieces under a certain size will be thus carried away with the coal, and when treating coal that is intended for the manufacture of metallurgical coke this is a matter of the utmost importance, and it is in this respect that all the gangue possible should be thoroughly separated from the coal. Machines of the vanner type, such as Craig's Patent Washer,

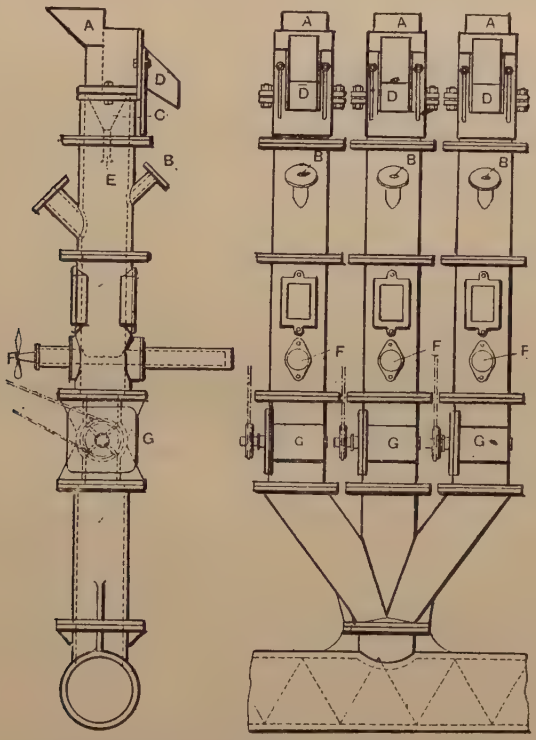


Fig. 21.—Coal Washing Plant at Llwynypia Colliery.

therefore, perform this operation more perfectly (without the risk of the finer particles of gangue becoming mixed with coal) than the jig machine type; but for the former the coal must first be reduced to powder to be treated efficiently.

A very ingenious washing machine has been designed by Mr. Draper, and installed at the Llwynypia Colliery, S. Wales. The following is a description of this apparatus, illustrated in fig. 21.*

"Fig. 21 is a diagram of a 5-ton per hour unit. The sized coal in its wet condition enters the feed hoppers A. (It should be understood, first, that the

* From the *Iron and Coal Trades Review*, July 5th, 1918.

whole apparatus is filled with water connected at the inlet pipes B with a head supply tank and outflowing over the sill D, this last being the overflow for water and washed fuel.) The unwashed coal passes downward into the internal cone-shaped device C, where it meets an upward current of water of suitable velocity just to overcome the gravity velocity of the falling coal in the water, when, of course, the fall is arrested and its direction reversed, so that it passes over the sill D. Meanwhile the heavier grains of shale and other impurities continue to fall, and, passing downward through E, finally enter the spiral conveyor for delivery to the shale elevator.

"In the original plant, although the complete operation was under observation, no special arrangement was made to facilitate sampling of the shale. It is obvious, however, that such an arrangement is very desirable, constant and systematic sampling of any coal washer being perhaps the most important, as it is certainly the most neglected, operation connected with these machines. Mr. Draper has devised an ingenious sampling valve F. This is merely a hollow tube sliding in a chamber, which will retain a section of the stream of falling particles and can be drawn out for inspection without disturbing the action of the separator, though, as in the old plant, glass chambers, in which are star valves G, are fitted. These, rotating at about four turns per minute, discharge the shale into the shale conveyor already mentioned. There remains only the inlet to describe. This consists of a flanged union to which a compensating air and water-balance head is fitted for the purpose of equalising the effect of separation taking place in the coned portion of the apparatus due to uneven feeding, etc.

"Applied to a large plant, the units as shown in fig. 21 are multiplied according to the capacity required. The coal for treatment, in the form of slurry from the main washery, dust from the screens, and brushings from the several collieries, is passed by the usual form of scraper conveyor into a large concrete settling tank. It may be noted in passing that this portion of the plant formed the slurry recovery for the main washers prior to putting down the fine coal units. The conveyor delivers by a chute to the main elevator, which in turn delivers at 45 feet elevation from rail level to a revolving screen. This screen is a particularly interesting portion of the plant, as hitherto we believe no attempt has been made to effect a separation of wet coal the size of which ranges from $\frac{3}{16}$ inch to $\frac{1}{100}$ inch. The screen in question revolves partially submerged in water in a rectangular screen hopper shaped into four separate inverted pyramidal compartments, which receive the sized coal divided according to the mesh of the different sections of the screen into various sizes, as follows: —Over size, $\frac{3}{16}$ inch, $\frac{1}{8}$ inch, $\frac{1}{32}$ inch, and through $\frac{1}{32}$ inch, the proportions of these sizes being approximately 20 per cent. between $\frac{1}{8}$ inch and $\frac{3}{16}$ inch, 40 per cent. between $\frac{1}{8}$ inch and $\frac{1}{16}$ inch, 25 per cent. between $\frac{1}{16}$ inch and $\frac{1}{32}$ inch, and 15 per cent. below $\frac{1}{32}$ inch, the whole of the coal which passes over a $\frac{1}{100}$-inch mesh being recovered. The coal passing through this mesh amounts to no more than 2 per cent., and as the ash content is approximately 45 per cent. the loss is not worth consideration.

"Star valves attached to each compartment control the coal and water. These valves are chain-driven at about 6 r.p.m. From the star distributor valves the fluid slurry passes over chutes to the tubular separators, the action of which has already been described. The washed fuel passes over $\frac{1}{100}$-inch mesh draining chutes, and thence to the waggons on the sidings, where drainage is effected before the coal passes to the ovens.

"Coal coming over the washery contains 15 per cent. of dirt, with a fixed ash

content of 5·5 per cent., and the analysis of the washed coal shows no more than 5·6 per cent. ash. The washed fines make an excellent mechanical coke. As a matter of fact, fuel which in the ordinary way would be used for the second-grade coke (at Llwynypia two qualities are made) after washing is found suitable for the highest quality of foundry coke.

"It will be obvious, of course, that the apparatus is equally suitable for dealing with larger sizes of fuel, and should prove particularly valuable for the recovery of the coal from spoil and waste heaps, as also with coal from dirty seams."

Another coal washer of simple construction is the "Elliot," made by the Hardy Patent Pick Co., and which has now been on the market for several years. An improved type of this machine has now been made, and is as follows:—

The "Elliot" Coal Washer consists of a machine with long troughs, as will be seen in the illustration (fig. 22). These are made of sheet steel or cast iron,

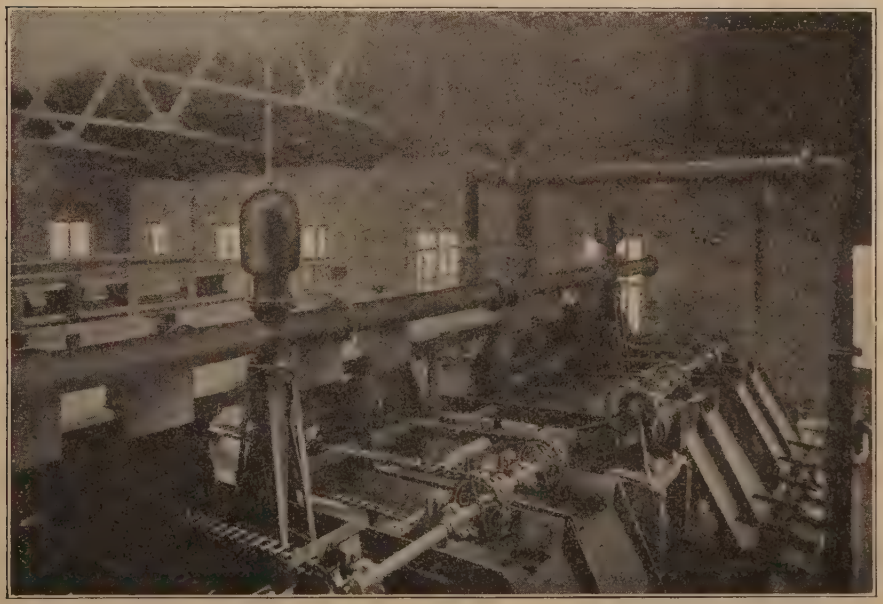


Fig. 22.—"Elliot" Coal Washer.

The bottom is flat, with sloping sides; the bottoms of the troughs are 2 feet 3 inches in width and the top is 3 feet 3 inches. There are two sprocket wheels placed at each end of the trough, carrying two endless chains, to which are fixed a number of scrapers: these scrapers are formed of the same section as the lower part of the trough, and travel from one end of it to the other, then return overhead, as will be seen in the illustration. They keep the coal and gangue continually mixed up, while the water carries away the lighter coal. The gangue is carried away by the scrapers and delivered over the end of the trough. The water carrying the coal is drained into settling tanks for the recovery of the fine coal. The troughs are set at an angle, so as to drain off the water by gravitation.

It has been shown in treating of the charge of coal for the coke oven, especially that intended for the longitudinal by-product recovery coke oven, that it should

be as free from moisture as possible because the amount of water vapour contained in the wet coal absorbs heat from the walls of the ovens in evaporating it. It is therefore surprising that so little attention has been paid to this side of the process of coal carbonisation, that no serious attempts have been made to deal efficiently with the excess of moisture on the large scale, beyond that which is done in the storage bunkers, where the surplus water drips out and drains away; this cannot be successful during the winter, if severe weather is prevalent, when the water coming from the bunkers is freezing and the drainage being arrested. There are creepers and conveyors used for the purpose of draining off the surplus water, but this method is also slow and inefficient, especially when all the ovens are at full work and the demand for coal to put into the ovens is at its maximum.

Bunkers have been designed with louvre openings through which the water drains away, but the storage of large quantities of wet coal means a very considerable capital outlay, as the bunkers are rather an expensive item.

In the future a more rapid and practical method may be performed by some kind of hydro-extractor, which may be automatic in action, the wet coal being dropped periodically into it from a shoot above; while after the desiccation of the coal has been completed to the extent required, a scoop could also be automatically introduced to scoop out the coal, and if the scoop was attached to a tubular arrangement the coal could be delivered straight into the conveyor, whereupon another charge of coal could be let into the hydro-extractor. This matter is pointed out here, as the author has seen a great amount of damage done to the interior of coke ovens by the action of surplus water in coal, this water generally draining down to the lower parts of the oven and, being cold, acts upon the red hot firebrick lining the oven, and cracks and splits up the bricks. Of course, there are certain bricks that will stand this severe treatment, but they may be at a great distance with heavy carriage charges on them, and may in other respects not suit the class of coal that is being coked, whereas on the other hand, first class firebricks, capable of standing great heats have been ruined in a very short time by the water thus attacking them.

In any case excessive moisture is to be avoided and any process whereby the moisture is reduced may in the long run compensate for the delay to the commencement of the coking period, by reason otherwise of the desiccation of the coal in the oven and the extra amount of fuel thus expended in drying off the surplus water.

Absolutely dry coal in the form of powder, on the other hand, could not be used conveniently owing to the dust created in charging the oven. This dust would ascend into the gas exit pipes, settle on the tarry surface and soon block them up; there is also the danger of explosion when the dust coal first meets the red-hot brickwork in the ovens; moreover, the presence of, say, 5 per cent. of moisture in the coal is beneficial as it tends to the consolidation of the coal in the oven and the production of solid hard coke.

The whole question of draining off the water only applies in particular to the fine, comminuted coal destined for the coke ovens; the nut coal is much more easily drained in the storage bunkers or even on the conveyors.

The Flotation Process.—This process, as designed by the Minerals Separation Company, consists in passing the coals, which are ground to pass through a screen of $\frac{1}{10}$ inch, through an apparatus, where the pulverised coal is mixed with from three to four times its weight of water. To this mixture is added the reagent, which may be oil or coal tar product or soap. The mixture with the reagent is then agitated in the flotation box in the machine illustrated in figs. 23

and 24. The dimensions of an ordinary machine for dealing with from 600 to 1,000 tons in 24 hours are 37 feet 6 inches in length, 16 feet in width, and 15 feet

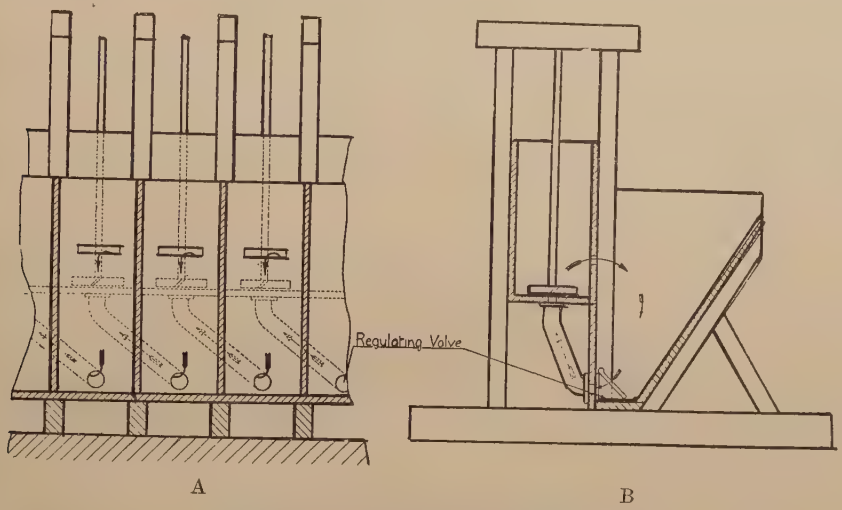


Fig. 23.—Plant for the Flotation Process.

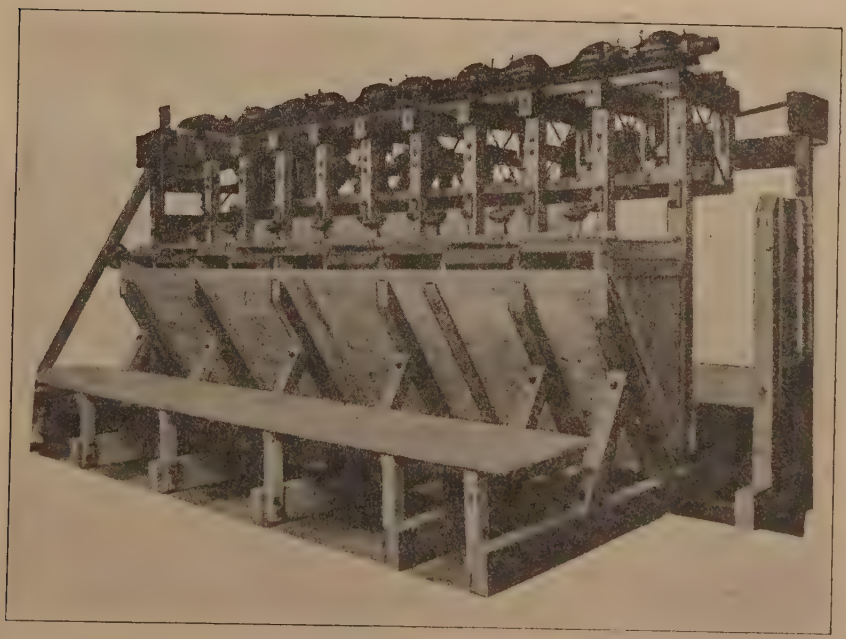


Fig. 24.—Front View of Plant for Flotation Process.

3 inches in height. The machine consists of 8 mixing boxes or divisions, with 8 froth boxes. The first one receives the charge for treatment. In these boxes

are placed agitators with vertical shafts operated by gearing from the horizontal shaft, running over the whole length of the machine, as seen in the illustration. The agitators are constructed with four blades or paddles. These agitators work the mixture up into a froth which rises to the surface of the water carrying the particles of coal clinging to the surface of the bubbles. This froth is then transferred from the mixing box into the compartment immediately in front of it, which is formed with V-shaped bottom, and termed the flotation box, as shown in section in fig. 23 and in front elevation in fig. 24. From this compartment, the froth then passes on to undergo the same treatment—that is, into the next mixing box, then into the flotation or froth box, and so on—each division

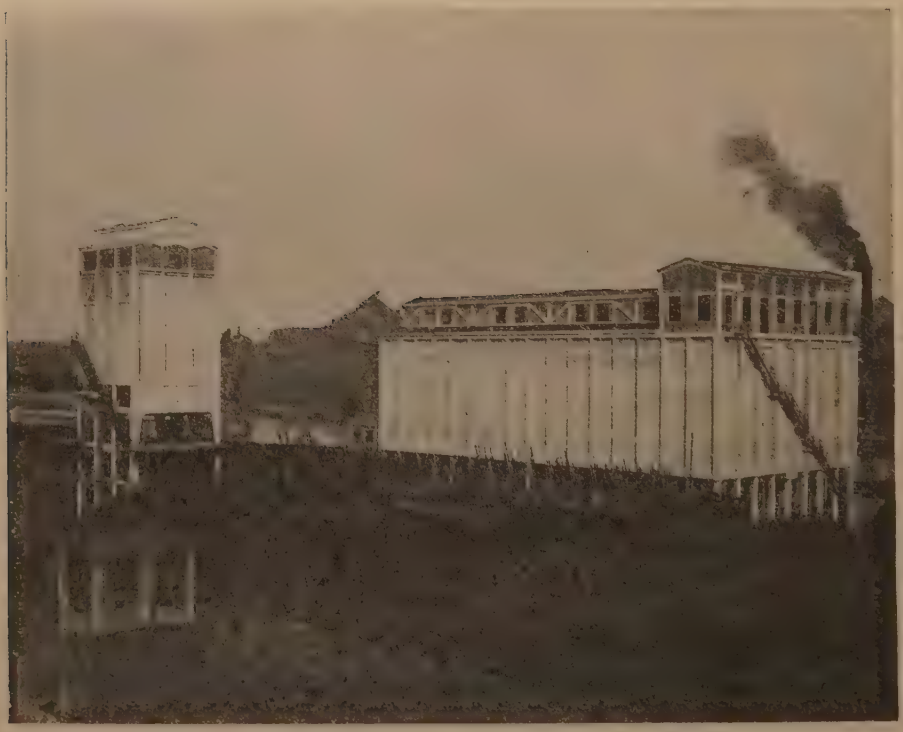


Fig. 25.—Storage Bunkers for Coal.

taking up more coal and frothing or floating it as it passes from division to division. Where the coal is mixed with "shale" or "clay," this is separated by one of the lower boxes after the high grade coal has been taken off, by the addition of a further portion of "paraffin," or similar oil. By this additional oil the bone coal is now separated from the shale or clay, such coal generally containing from 12 to 15 per cent. of ash. The residue consisting of the gangue is run to waste from the last box. It is stated that about 1 lb. of the reagent is generally required to treat 1 ton of coal.

The following are some of the results obtained at the works of the Powell Duffryn Aberaman tip :—

	Weight.	Ash.	B.T.U.
	Per cent.	Per cent.	Per pound.
(1) Raw Coal, ...	100	70·4	2·280
Washed product, . . .	15	15·6	12·450
(2) Raw Coal, ...	100	67·6	5·230
Washed product, . . .	21	10·5	12·280
(3) Raw Coal, ...	100	48·5	4·390
Washed product, . . .	30	10·5	12·680

The above were obtained from " damp " materials containing about 60 per cent. of ash.

The following table shows the result of some tests made with that process:—

RESULTS OF TESTS.

	Original.		Cleaned Product.		Tailings.	
	No.	Ash.	Weight.	Ash.	Weight.	Ash.
CRUDE COALS.						
A—*Coking.*		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
	1	12·4	87·8	3·8	12·2	72·4
	2	24·2	75·9	5·2	24·1	78·5
	3	15·8	83·2	5·4	16·8	76·0
B—*Industrial (non-coking).*						
	4	25·5	73·8	8·9	26·2	84·5
	5	27·0	68·3	9·0	31·6	76·0
	6	21·8	69·8	7·3	30·1	74·4
	7	28·2	66·7	9·4	27·5	78·8
SLACKS.						
	8	30·0	68·9	12·2	31·1	80·0
	9	30·5	71·0	9·6	29·0	86·5
SILTS.						
	10	35·5	60·2	8·1	39·8	74·0
	11	33·8	48·5	11·7	51·5	78·0
	12	21·5	83·8	9·9	16·2	81·5
	13	45·2	59·0	12·5	40·5	82·8
DUMPS AND WASHERY WASTE.						
	14	74·0	16·8	13·0	83·2	86·6
	15	40·3	53·0	7·9	47·0	75·8
	16	61·2	30·2	10·1	67·8	86·1
	17	76·0	14·5	13·5	83·0	87·6
	18	62·2	24·3	9·6	70·7	84·8
	19	62·0	22·8	9·25	71·0	82·7
	20	75·0	16·2	14·0	83·8	88·5
	21	63·8	28·7	10·8	71·3	86·5

Another item in the washing of coal is that of using water containing clay, or coal containing a clayey gangue, it always being a most difficult matter to deal effectually with clay on account of its settling with the fine coal, and thus consolidating it in the washing machines. This is to a very large extent

overcome by the introduction of agitators or stirrers that keep the materials always in motion and prevent settlement on the sieve. Some processes of coal washing even claim to eliminate the clay entirely and to deliver it for brick making. Should such be successful it would seem that they would be only capable of economic working when applied to some special class of coal, carrying in general clay in sufficient quantity to be thus disposed of. An

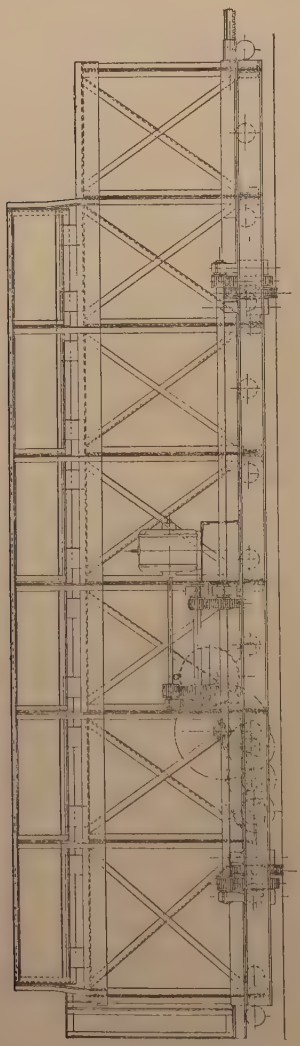


Fig. 26.

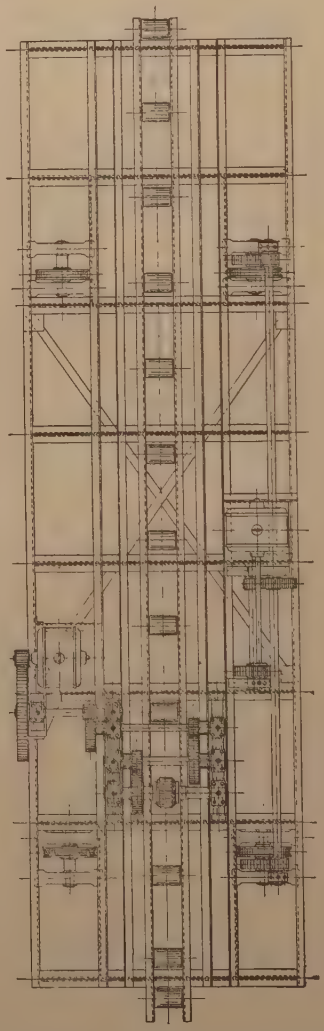


Fig. 27.

illustration of a coal storage bunker by the Coppée Coke Oven Company is shown in fig. 25. It is constructed in ferro-concrete and erected at Liège in Belgium, and has a capacity for 1,000 tons of coal.

Coal Pressing and Charging.—The Horizontal By-product Coke Oven has passed through various stages of development, and one of these stages has been the means adopted to acquire a larger output from the ovens, and at the

same time to consolidate the coke. The older system was to fill the ovens from charging holes in the roof, over which a tramway was placed, the charging waggons being pushed over the charging hole, and the contents dropped into the oven. This method, however, did not give an even charge, and after the oven had been charged through the holes in the roof the workmen had to introduce long rakes to level down the charge to a uniform height, but the coal was loose in the oven; the height being under 6 feet, the weight of the coal did not exert any pressure to consolidate it. This was overcome by the process of first filling the damp coal into an iron box, the shape of and a little less than the size of the interior of the oven. This will be better realised by reference to fig. 26, which shows this box in elevation. Fig. 27 is the same in plan, and fig. 28 is the same in cross-section, showing the method of filling the box from above. These are by the Coke Oven Construction Company.

Too much may have been anticipated from this method of charging with the idea of improving the consistency of the coke by the supposition that treating the coal thus previous to charging into the coke oven actually makes the coke very much denser and harder. The one fact is, that a larger charge can be put into the oven, but to make coke denser and harder requires something more than simply cramming more into the oven; it requires prolongation of time during the coking period, as will be more fully explained in a future chapter when dealing with the theory of coking. No doubt there is a certain amount of extra density produced, but this cannot be much, owing to the fact that the box containing the coal is smaller than the interior of the oven; pressure has been released from the coal and it is thus again loose in the oven, theoretically not even touching the sides of the brickwork, if the block has attained the stiffness necessary to make it stand upright. This, however, is not possible and the immediate effect of the introduction of this damp mass of coal into the red-hot oven will be for the steam developed in the mass of coal to burst away the coal and disintegrate the mass.

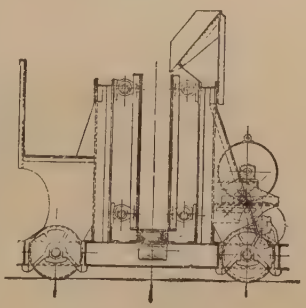


Fig. 28.

On the other hand, had the coal been stamped or pressed into the oven itself, instead of into the charging box, there would have been no room inside the oven for this decrepitation to take place; the coal would have been tight against the sides of the oven, as in the vertical ovens, and a very dense coke would thus have resulted. Owing to the fact of the coal being released from the stamping box into the oven, which is larger, these desired effects are very much discounted.

Nevertheless, it has been a very great improvement on the former method of charging by the roof with the subsequent levelling of the charge by the workmen.

It is wise, however, that the dimensions of coal thus introduced into a horizontal coke oven are less than those of the oven, otherwise a serious bulging of the walls would inevitably follow, as would be the case if the coal had been pressed into the oven as already suggested, because the coal then, under the heat of the oven, expands, and should the block of coal be pressed in tightly, the walls of the oven would certainly give out under the pressure from the expanding coking coal. The walls in a horizontal oven cannot stand much internal pressure owing to the flue construction in their interior, and the

difficulty of stiffening the walls makes it an impossibility, in a long row of ovens, to form the walls throughout the entire batch to withstand internal pressure. Unlike the vertical oven described in another chapter, and designed specially for this purpose, the walls are formed as an arch and bound on the outside with steel bands. Such binding and strengthening would be out of the question in a batch of horizontal ovens where the roof is practically the only stay the walls can have.

The chief advantages, therefore, that this method of charging can have, are the larger charge that can be inserted into the oven, and the pressing together of the particles of coal, thus making a better conductor for the heat after the first two or three inches have been coked against the walls, as the coking process proceeds. There is a drawing away to both heated sides of the oven of the coal undergoing carbonisation, and the denser the coal is towards the centre, the denser will be the coke, owing to the fact that the denser the charge is at this period, the stiffer will be the backing for the purpose of squeezing the coal, in the soft state, against the hot walls, and the stiff centre core of uncoked coal. But when the coking has proceeded a certain distance in from each wall, this backing ceases to be effective, since, as already pointed out, the charge, in the process of coking, draws away from the centre. This is exemplified when the coke is drawn from the oven, where the wall of coke is split down the centre, till near the bottom, where the weight of the charge has given it the required resistance to the expansive pressure on the one hand and the contraction due to coking on the other, a more solid coke being found towards the bottom of the oven.

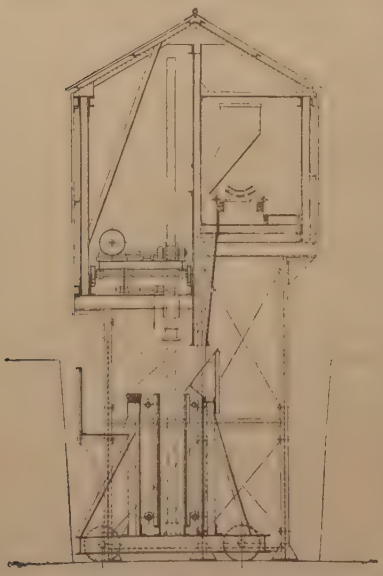


Fig. 29.—Single-Ended Stamping Box.

The charge is introduced into the oven from the box in which it is stamped or pressed by means of a ram propelled by a machine running on rails alongside the ovens, on the opposite side to that on which the coke is discharged. The same machine is used, when the coking process is finished, to push out the charge on to the quenching platform.

The stamping box and the machinery operating it is of the following description, given to the author by the Semet Solvay Coke Oven Co.:—"The charging machine serving a battery of ovens is mounted and travels upon the same rails as the ram for pushing out the finished coke from the ovens, and consists of a long box, almost the same (a little less) as the interior dimensions of the coke oven. Its bottom is formed of a sheet of steel, termed the charging peel. It has a flat surface on the top, with a rack of teeth on the underside, and a 'thrust plate' at the back end, the full height of the box. The front of the box, facing the coke ovens, is closed with a hinged door which is kept closed until the operation of stamping and loading the box has been accomplished. The machinery for stamping and compressing the coal in the box is mounted over the latter on a superstructure, and while the coal is being delivered into

the box the stamping machine is made to traverse the box from one end to the other, reversing automatically. The coal is delivered by a conveyer directly into the box and as it is thus delivered along the box, the stamping machine follows, and thus backwards and forwards each layer of coal charged in to the box is pressed down.

"When the box has received the requisite charge of coal, the door at the end next the oven is opened. The oven door is also opened, the sides of the

Fig. 30.—Double-Ended Coal Compressing and Coke Discharging Machine.

box slightly released to prevent friction against the upright walls of pressed coal, and the charging peel with this wall of coal on it is now pushed into the oven, the oven door is closed, and the charging peel withdrawn."

The charging machine is sometimes combined with the discharging coke ram, but this is not always convenient, and sometimes causes delays when repairs may be required to the stamping machine, while the coke discharger may be required at the same time to discharge some other ovens. An illustration, in cross-section, of a separate stamping box without the discharging ram, is shown in fig. 29. The arrangement for supplying the stamping box with

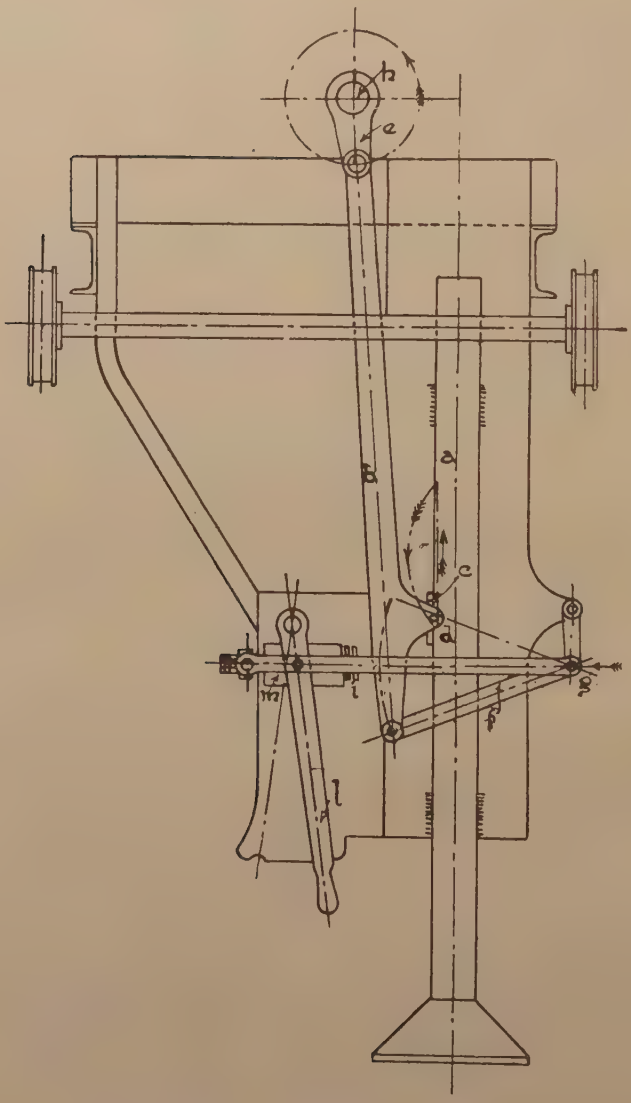


Fig. 31.—Details of Coal Stamping Machine.

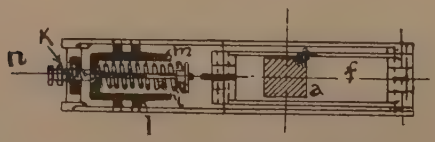


Fig. 32.—Details of Coal Stamping Machine.

coal direct from the bunker usually consists of a rubber band conveyer: Fig. 29 shows a stamping box designed by the Coke Oven Construction Co., Ltd.

As previously stated, before the introduction of the compressing box system of charging the ovens, they were charged through openings in the roof, and many ovens are similarly charged at the present time.

The coal charging waggon is mounted on wheels that run on rails along the roof of the ovens, and the pushing or discharging ram also contains a levelling apparatus for levelling the coal in the ovens, which is brought into action after the charge has been inserted in the oven. There is also a door lifting apparatus attached to this machine.

The compression of coal for coke ovens by means of the box is more especially applied to coal rich in volatile constituents, which, generally, in the horizontal ovens, if uncompressed, does not yield a first class coke, whereas other classes of coal do not require to be thus treated, and yield first class coke for all practical purposes. Of course there are certain coals that will not even coke in the horizontal ovens when compressed by the stamping machine, for the reasons explained in another chapter dealing with the theory of coking. Such coals can only be satisfactorily coked in vertical ovens, *e.g.*, the Lanarkshire coals, containing upwards of 40 per cent. of volatile matter, which cannot be coked in horizontal ovens, but from which first-class coke has been made by the author in vertical ovens.

An end view of a stamping and discharging ram machine, working at Messrs. Pease & Partners' collieries, and erected by Messrs. Simon Carves & Co., is shown in fig. 30. It has two compression boxes, one on either side of the discharging ram. One of the boxes will be observed with the end door taken off and the other fixed in position to receive the charge of coal. Referring to figs. 31 and 32, which show in detail the stamping mechanism, on the shaft *h* is fixed a crank *e*, which works a rod *b*, fitted on the end with a pin upon which works a radius arm *f* at one end; and the other end of the radius arm has a similar pin working in *g*. The friction plate *c* has upon it side spindles *d*, which engage in *b*—the action of the crank *e* will therefore move *d* when going towards the right almost perpendicularly along the dotted line shown by the arrow. When it has arrived at its full height, and the crank *e* begins to make its return semi-revolution downwards, the friction plate with its catch pins leaves the stamper shaft *a*, and makes a curved line of descent as shown by the arrows; when the stamper rod is thus released the stamper falls. It will be observed that the fulcrum *q* is not a fixed point, but moves backward and forward; when moving in the direction of the arrow it presses back a spring *i*; this spring keeps the plate *c* in position during its upward rise against the stamp. The tension of this spring is capable of adjustment, independently of the set screw *k*, by means of the screw *n*, fig. 32. In order to arrest the working of the stamp by the attendant, the lever *l* carrying the bush *m* is placed to the left, opposite to the position shown on the drawing, the plate *c*, therefore, in its upward movement does not engage the stamp, which remains inoperative. Two stamps can work from the same shaft set at a semi-revolution of the crank *e* apart; they therefore balance each other, that is, while one is up the other is down. The stamps can also be made to work separately, or be arrested at any height by means of eccentrics. This machine is driven by a 5 h.p. electro-motor, each stamping hammer making 70 strokes per minute.

CHAPTER IV.

THEORY OF COKING.

To give an accurate, detailed description of how the entire process of the destructive distillation of coal is carried on is a problem surrounded with great difficulties, since a considerable part of the process can only be assumed or ascertained by inference. The material under treatment is dense, opaque, and black in colour; it is heated out of contact with air, and the operation of coking or carbonisation is carried on where observation is impossible—*e.g.*, in the interior of retorts or ovens made of materials also opaque—while the process itself produces vapours, gases, and liquid hydrocarbons that form opaque deposits on glass retorts or apparatus. At the same time, conclusions can be drawn from evidence provided by the results obtained, such as the nature and form of the coke produced from coal of a certain analysis; from the gases, tar, and other by-products; from the behaviour of coal at different degrees of temperature, and by various other means that may be employed to ascertain how certain effects are produced.

When a piece of bituminous coal (bituminous is here used as a general term, although it is a misnomer, as it has been ascertained that coal does not contain bitumen), or what may be definitely known as caking or coking coal, is heated, gas commences to be given off. As the heat is continued and increased, the coal commences to soften and then melts, but this does not take place in the way an ordinary substance would soften and melt, as, for instance, wax; the softening and melting are only temporary phases of the physical change that is being made in the coal, which is subsequently, and very soon, succeeded by a rigid stiffness which is permanent.

All coals have not the same propensities for softening or melting, and these qualities seem to be confined to the class of coal termed "coking" or "caking." In this class of coal there are characteristic differences to be observed, which make a wide separation between them in their ultimate products of carbonisation.

The coals that readily melt into a thin liquid paste as the gaseous contents are expelled do not swell up, but form small bubbles, the walls of which, being very thin when distended, soon burst and collapse, the gas escaping very readily without much disturbance to the bulk of the soft liquid paste.

The coke resulting from this class of coal is dense and hard, the cell structure resulting from the gas bubbles that have been formed towards the end of the melting period. These bubbles are small, and are formed by the residual gas as it expands in the melted coal just as it stiffens, probably momentarily, and then carbonised in the agglomerated coke.

When a piece of bituminous coal burning in an ordinary domestic grate is observed, the phenomenon of distillation is pretty well illustrated. The jets of smoke puff out, followed by a jet of flame as the gas takes fire; the gas for a period then becomes exhausted; the soft, molten coal swells up into a bubble under the influence of a second supply of gas evolved, and a small dome is

formed, which bursts, and again the imprisoned gas escapes, together with the flow of a small portion of tar that has condensed inside the dome of the gas bubble; the jet again takes fire and burns with its characteristic smoky flame. This process continues like a miniature geyser over the burning coal, until the heat has exhausted the gaseous contents and ultimately consolidated the molten skins of the successive bubbles, forming a concentration of half-formed cells on the outer surface with collapsed ones beneath. These are the residues of the larger bubbles formed on the outside of the coal, where no hindrance to their development has been exercised. When, however, this process is carried on under the pressure of an overlaying stratum of coal that has undergone the process of carbonisation, and forms a consolidated solid barrier to the free development of the bubble, the resulting phenomenon is different, and the important factors of confinement and pressure exert an influence on the character of the bubble under the new conditions.

When the exudation of gas and tar from coal undergoing carbonisation, as in an ordinary Beehive oven where the heat is obtained from the combustion of the gases and coal inside the dome of the oven, the pressure of the already formed coke (after the first period of surface carbonisation has passed, as characterised by the procedure detailed above) prevents the development of bubbles, or any concatenation of them or their residue of consolidated carbon as such; but instead of the bubble of gas expanding upward, as in the surface action, the gas is forced to find an exit by the passage of least resistance. This is only possible now through the coal that is uncoked and unmelted or softened. The stratum of coal thus immediately underlaying the zone of molten coal is one of great porosity by reason of the small particles of coal not being able to form a perfectly gas-tight solid stratum. Under these conditions the gas finds an exit *per descensum* through these very small channels between the particles of unchanged coal.

The bubble formed by the escaping gas in the region of molten coal above is very small, and its existence is transient; being pressed from above it is flattened and compressed, and it is only those bubbles that are formed last—that is, nearest to the heated, incandescent coke above—that are caught, suddenly carbonised, stiffened, and finally absorbed in the resulting coke as it progresses downward.

As the gases make their escape downwards, and sideways, to the nearest crack or crevice in the superincumbent mass of coke, the tarry matter carried by them is deposited upon the fine grains of cool coal through which they pass on their way to the exit.

This tarry matter is the real binding or coking material of the coal, and in those processes in which the pressure and confinement alluded to above are absent (as in the retort process of making illuminating gas, where the layer of coal is shallow and the gas has a practically free exit) this binding material is lost, and is condensed from the gas, on cooling, in the copious amount of tar produced.

In the process of carbonisation of coal, however carried on, where pressure exerts an influence in driving the gas through a cold stratum of coal, this acts as a filter on the fine particles of tar contained in the gas. It is a well-known fact that this finely divided tar suspended in coal gas cannot be extracted easily unless the gas is cooled. This extraction is one of the difficulties that is experienced with coal gas given off from processes of carbonisation at high temperatures when these tarry matters have to be eliminated completely in order to allow

the gas to pass on to undergo further treatment for sulphate of ammonia and benzol.

In those processes, therefore, such as the old Beehive and the vertical coke-oven processes, where the gas is retained under pressure and its only exit is through a stratum of comparatively cold coal, finely divided, the tar is automatically extracted, and ultimately fixed, carbonised, and coked, forming by this means the purest and hardest coke. The tar carried by the escaping gas leaves behind it all the ash contained in the original coal; coke, therefore, formed from these tar deposits is the purest coke, free from ash; and the greater the tar deposit the greater will be the coke carbonised from the coal. The quality of the coke will rise in proportion to the amount of carbonised tar in the coke.

The tar does not only form coke of the best quality and of the highest purity, but it acts on the uncoked and cool coal as a medium by which it is further enhanced in coking value, acting as a binder. If it were possible to extract all the gas and tar from coal, previous to the coking or melting period, the coal would not coke.

This is proved by the torrification of coal –that is, when it is submitted to a low-temperature distillation, enough to expel these hydrocarbons, any subsequent heating does not result in the formation of coke. as made under normal conditions. It is also a fact that the best coke can be made by heating coal under certain conditions to a high temperature rapidly; and if the conditions of confinement and pressure be observed, the resultant coke will be of the highest quality. On the other hand, low-temperature distillation of coal produces exceedingly soft and porous coke when carried on without pressure or confinement, with the obviously increased amount of tar, which is generally out of all proportion to the restricted volume of gas produced.

The higher the temperature of carbonisation generally employed on certain classes of coal the more gas is produced with less tar, and the lower the temperature of carbonisation the less gas is produced and the more tar. By the former method hard coke is produced, by the latter soft porous coke.

The principles underlying the carbonisation of coal under pressure and high temperature are such as to alter completely the results of such carbonisation when compared with results attained by ordinary methods, and these principles have hitherto been neglected in the treatment of certain coals that have proved a failure in the ordinary by-product horizontal oven, but which under these conditions of pressure, confinement, and high temperature have been most successfully carbonised with a resultant excellent, dense, hard coke. Coke certainly is produced in ordinary horizontal by-product ovens from this class of coal, but it is in finely divided powder and absolutely useless.

This matter will be referred to again in describing the process of carbonisation in vertical by-product ovens.

With regard to the process of **carbonisation under the conditions obtaining in the Beehive oven** and the vertical by-product coke oven processes, where the carbonisation as already stated is carried on under pressure and confinement, the gas making its escape by the exit provided in the uncoked coal. This escape, in the case of the former oven, takes place toward any opening that may be nearest. In the Beehive oven, the coking process by proceeding downwards leaves behind it the already formed superincumbent coke, now heated to incandescence, and by the continued heat applied to it a reaction sets in—that of contraction. Whereas in the first instance the exit of gases from the soft, molten coal tended to extend and swell it up, forming cells or bubbles in

it, but as soon as the process of solidification commences, under the continued heat, gas continues to be expelled.

The carbonised and solid crust thus formed cannot be diminished by the loss of these gases without curtailment in bulk, and this is followed by contraction. The contraction of the already formed incandescent coke is always at right angles to the line of heat, and of the progress of the coke formation —that is to say, in the Beehive process the contraction is in a horizontal direction, producing cracks or fissures in an opposite or vertical direction, and in the case of other ovens, where the heat is applied in a horizontal manner, the contraction is vertical, and the cracks or fissures formed thereby are in the horizontal direction.

Now, since in the Beehive process the gases escape underneath and along the impervious layer of soft, amorphous, molten coal, and through the powdered cool coal, it makes its way to the nearest vertical crack or fissure in the upper crust of coke and escapes into the upper regions of the oven, where it takes fire and burns. A reference to fig. 33 shows a section of a Beehive oven during

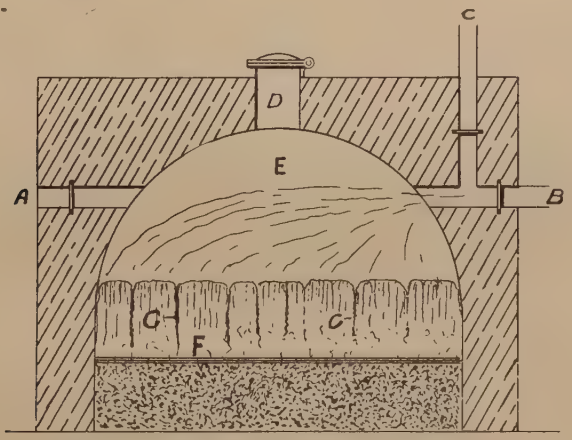


Fig. 33.—Section through Beehive Coke Oven.

the coking period, somewhat advanced, with an overlaying layer of already formed incandescent coke, as at F. The dark line represents the soft, amorphous, molten coal, dividing the coked from the uncoked coal. The cracks or fissures by which the gas finds its way into the oven above the coke, where it is ignited and burned, are shown at G.

On making its escape the gas often forms fantastic and beautiful forms on the coke, in the shape of floral wreaths, shown in fig. 34 at A, B, C, and D, and also fine hairs or wool, as shown at E. The process by which these extraordinary formations are produced in the Beehive oven is more or less that explained above, where the gas making its escape from the molten, amorphous mass of coal underlaying the incandescent coke escapes at the outset into a crack or fissure D, D (fig. 35), the bottom of which is cool coal, unmelted, as shown at E. The gas carries up with it from the cool region a certain amount of tarry matter, and, as in the crack or fissure, there is free exit for the gas, the tarry matter along with a portion of the molten coal forms at first a bubble C (fig. 36), which is distended, rises in the tube at B, and then bursts at its apex

A. The gas blowing out at a small orifice A (fig. 37, B) deposits liquid tar on the edges, while another bubble ascends up the crater formed in the miniature volcano, as shown in figs. 36 and 37, which, on reaching the top of the crater also bursts with a puff of gas and deposits another ring of tar around the upper edge of the now hardened first crater ring, and so, as long as the gas

Fig. 34.—Coke showing Floral Wreaths.

can make its escape by this means, ring after ring is formed, and by its concatenation a continuous tube of carbon is produced; such a tube is only possible of formation where it is found enclosed between two adjacent pieces of coke, in a crack or fissure, because it is there protected from any crushing pressure or from any access of atmospheric air; otherwise it would soon vanish.

Such formations could not be formed on the surface of the coke, at the top, exposed to the oxidising influence of the air, because they would be consumed immediately they were formed.

These hairs or tubes are of considerable length, are very brittle and hard, having been ultimately carbonised and consolidated out of contact with air, and are formed of very pure carbon. It is quite possible that a great number of them are cut short in their growth by being prematurely clogged up with tarry matter, where the temperature is high, which prevents the gas escaping regularly and thus keeping the passage or tube open.

The excrescences forming floral-like designs on the sides of the coke are formed, in all probability, in the same manner, but instead of the tarry matters following the course of the gas through the tube, they are dispersed in the rind of lava flow over the side of the crater just formed, where the exudation of the gaseous and liquid tarry matters is more plentiful.

Where the gas as shown burning at C, C (fig. 35) carries any tarry matter

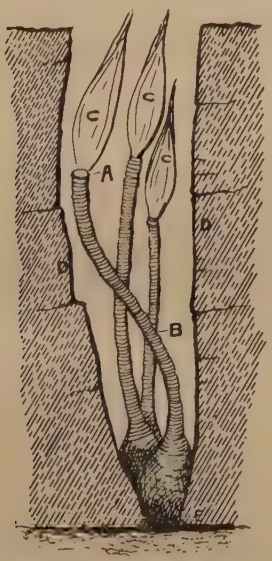
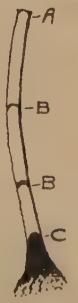
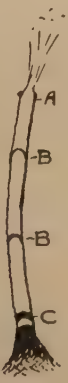


Fig. 35.—Formation of Coke Hairs.





Figs. 36 and 37.—Formation of Coke Hairs.

and impinges on the walls, D, D, of these crevices or cracks in the coke, a very hard and shining surface is produced by the deposit of a very fine layer of very pure carbon, spread over in extremely fine division or thinness of wash, filling up microscopical inequalities in the surface, and producing in some cases a very bright silver appearance. In other instances a dull grey or black smoky patch will be observed, more like a deposit of soot; probably this is where a jet of gas, with tarry matter issuing from the bottom of a crack, had caught fire, and impinged on the wall of incandescent coke; the air for combustion being extremely limited, a dense smoke would be produced, from which soot would be deposited.

When the process of **carbonisation** is **carried on in retorts** for the manufacture of illuminating gas, the temperature of distillation is comparatively low, and with the gas is given off a large quantity of tar. This tar, carried forward

by the gas, is deposited on the roof of the retort, forming by accretion a thick layer; when this deposit is examined it is found to have none of the characteristics of coke made by any definite process, but is of an extremely dense and hard nature, practically free from ash, being the product of the deposition of tarry bodies on the roof and sides of the retort. In fact, if it were not for this deposition of carbon, in the consolidated form, it would be practically impossible to have gas made by means of fireclay or firebrick retorts or ovens.

Fireclay materials used in the apparatus, furnaces, and ovens for carbonising coal is not the ideal material that one would like to employ for the purpose, because it is liable either to expand or contract, leaving fissures between the bricks; or upon the exposure to heat, to contract, and in the case of retorts, to split up into numerous pieces. It is the cementing proclivities of the gas-deposited carbon, which makes its escape between the joints of the new brickwork in a coke oven, or between the cracks and through the pores of a retort, so that these are gradually closed by the accretion of the deposit of these tarry bodies becoming carbonised and fixed, which ultimately (after a few days) makes the joints and the other apertures perfectly gas-tight. Not only does it make these gas-tight, but so braces and consolidates the whole that considerable gas pressure can be withstood after the process is complete.

In the **carbonisation of coal in the horizontal coke oven**—that is, in an oven usually constructed in blocks of 30 or more ovens—each about 5 to 7 feet in height, 33 feet long, and from 16 to 24 inches wide (the dimensions vary in the several different types, but the above perhaps embraces the whole of them), the coal is carbonised upon an entirely different principle from that of the Beehive oven. The ovens are fired externally, as will be shown in Chapter VII., where their construction will be described. The coal is either filled in from the top, through apertures designed for this purpose, and then levelled down, or it is placed in an iron box the length of the oven and slightly less in width and height, where the damp powdered coal is stamped and consolidated as it is filled into the box. As soon as the contents of the box are complete the sides are loosened, and a machine pushes the coal into the oven, on a false iron bottom called a peel, which is subsequently withdrawn.

The coal, although compressed in the box, is not to the same extent compressed in the oven, since the space occupied by the sides of the box is vacant and the top of the charge is without pressure; under these circumstances a larger charge is put into the oven, but the effect of compression is discounted by the fact that pressure is absent when it is most required, during the coking period, as will be shown subsequently. The coal thus charged, stands in a block in the hot oven, but not touching the walls on both sides, until the heat begins to desiccate the surface and steam is produced below; this expands the layer immediately behind it and decrepitation commences—that is, the outside desiccated skin commences to peel off and fall down between the block of coal and the hot oven walls, thus releasing the pressure of consolidation acquired in the iron box, while, as the process progresses, the steam and the exit of the gases soon disintegrate the mass. A section of a horizontal coke oven is shown in figs. 38 and 39, where the hot oven walls are represented at A, A and the coke, which has undergone considerable carbonisation, is represented at B, B, while that portion of the coal which has not been carbonised is shown at E within the dotted line F (fig. 38).

As the carbonisation of the coal proceeds in this process the heat is derived from the walls, A, A, in a horizontal direction, the coal swelling up locally along the line, F, as this line proceeds inwards from both sides; this line

represents the soft, pasty, molten portions of the coal situated between the already formed coke B and the uncoked coal E.

Coal being a very bad conductor of heat, the process of carbonisation makes its progress slowly, but during this progress the coal is changing its physical properties, and forming coke; the coke is likewise undergoing a material change. The newly formed coke immediately along the outside of the line F is soft, and at its maximum bulk, and solid, but as the coking period is prolonged it is subjected to rising temperature, depriving it of volatile matter and subjecting it to a process of contraction in a vertical plane at right angles to the line of heating, as shown by the cracks commencing at C (fig. 38).

This contraction goes on to the end of the process, the cracks or fissures developing, and the contraction of the mass of coke also making progress from both sides of the oven and from the top downwards.

There is also another peculiar feature in this process of carbonisation by which proof is given of the absence of pressure on the coal during the period of carbonisation. It will be observed when a coke oven has been charged and the coal carbonised and is ready to be drawn that, when the end door has been

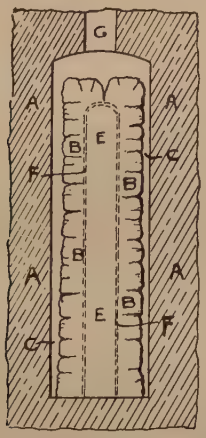


Fig. 38.—Vertical Section of Coke in Horizontal Oven.

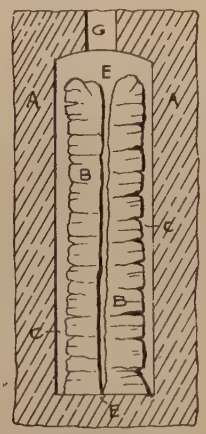


Fig. 39 —Vertical Section of Coke in Horizontal Oven.

removed for this purpose, and the ram is pushing out the contents of the oven in the shape of coke, the coke is divided into two separate walls, as shown in fig. 39 at B, B, with a considerable space between these walls of coke and also between them and the walls of the oven.

The space E, E (fig. 39) represents the contraction that has taken place when the coking period had developed beyond the dotted line, shown in fig. 38. In looking at the top of fig. 39, just below the orifice, G, in the roof, will be seen the first development of the formation of this interior space, by a crack or fissure. The heat penetrating the coal at the top develops this fissure and, when the carbonising period has reached the limit of the cool coal in the centre, this is softened; part of the soft, plastic coal adheres to one side and part to the other; then commences the contraction of the coke, by which means it is absolutely torn asunder into two separate walls, as shown in fig. 39, which represents a section of a horizontal coke oven when the carbonisation is complete and the coke ready to be drawn.

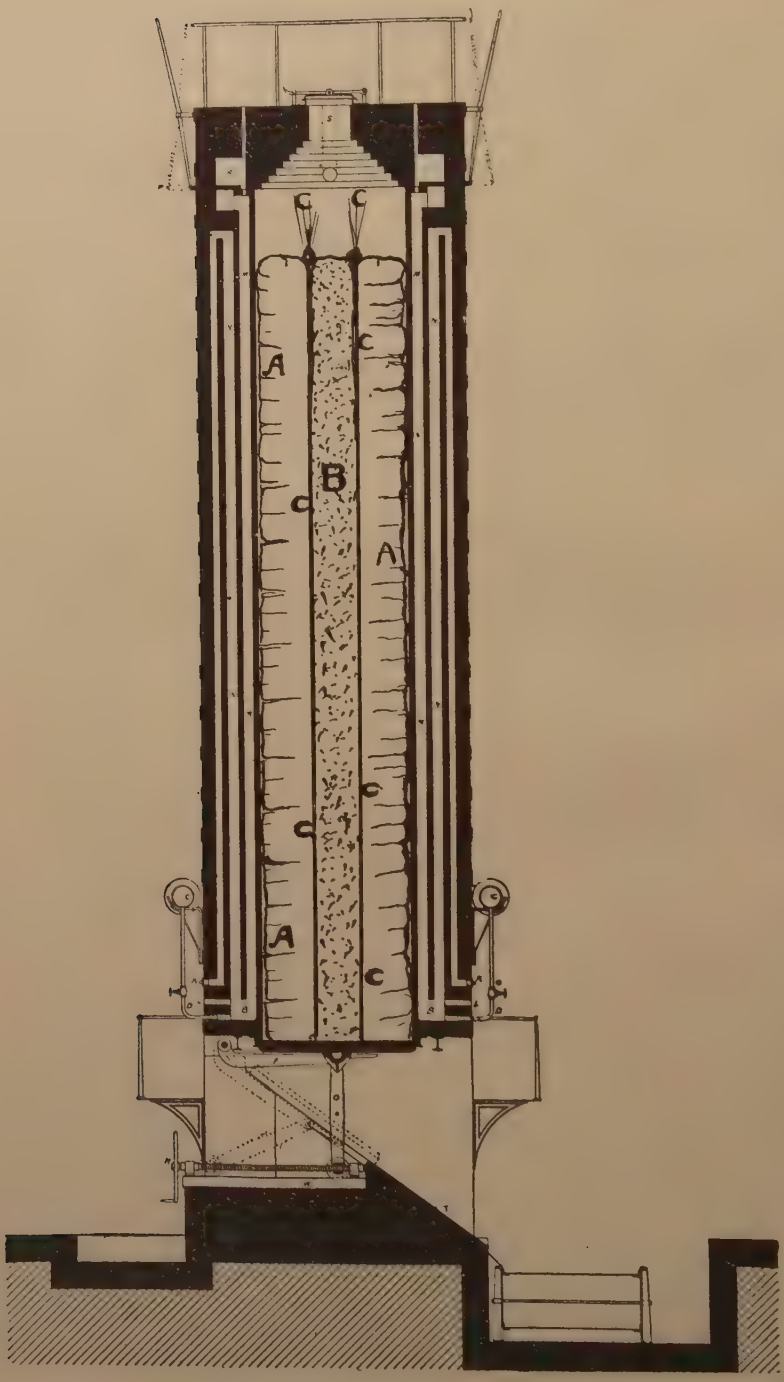


Fig. 40.—Vertical Section of Coke in Vertical Oven.

When the **carbonisation** is conducted in a **closed oven of the vertical type** heated externally, the process is similar to that of the Beehive oven as far as the production of the same quality and class of coke is concerned. The principles underlying and governing the two processes are alike in many respects, and coke is produced in the vertical oven of the same size, same appearance, and same quality, but denser than in the Beehive oven.

The vertical oven not only makes the best foundry coke, equal in every respect to the best Beehive coke, but it is capable of coking and forming solid, hard coke from a class of coals that otherwise are uncokable in an ordinary horizontal coke oven.

The oven shown in vertical section, fig. 40, and in horizontal section plan, fig. 41, was specially designed by the author some years ago for the Coltness Iron Company, Limited, of Newmains, near Glasgow, to coke their coal from the Lanarkshire coalfield. This particular coal contains very high content of volatile constituents, with a high percentage of oxygen and hydrogen. Several attempts to coke it had been made in different types of horizontal ovens, and quantities had been sent to different parts of the country for this purpose, with instructions to have the results of the carbonisation returned to the Coltness Iron Company. The author inspected one of the waggon loads of the product of carbonisation, which he was informed by the son of the manager had been carried out under his personal supervision in an "Otto-Hilgenstock coke oven" a short time previously.

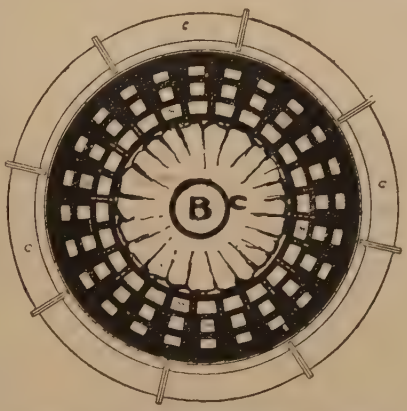


Fig. 41.—Horizontal Section of Coke in Vertical Oven.

The material consisted wholly of carbonised dust, in fine division, showing conclusively that coking had taken place, but in separate fine particles.

The theory which the author drew from this sample was that, owing to the high gaseous contents of oxygen and hydrogen, combining at the coking temperature at the critical moment to form water vapour, the coke was rendered uncakable, and was thus split up into the fine division in which it was received at the end of the operation. Reasoning upon this basis, it was inferred that the type of oven suitable for coking a certain class of coal of good coking qualities was not suitable for coking this coal, possessing coking qualities, but with additional exceptional restrictions.

The author then designed the oven represented in figs. 40 and 41, which was erected at the works of the Coltness Iron Company at Newmains, Lanarkshire, and charges of their coal weighing about 5 tons were filled into it. The oven was of circular form on plan, 3 feet 1 inch in diameter inside, and at first was constructed 25 feet high inside, but subsequently this was raised to 30 feet.

The oven was constructed on the recuperative principle; it was heated by gas obtained from the blast furnaces adjoining it, and the air for combustion was heated by means of recuperative flues shown in figs. 40 and 41 and marked N, N. The gas being conveyed to the oven in the pipes, C, C, surrounding it, with drop pipes, D, to the heating flues M, each flue had a separate pipe for gas

and a separate recuperative air flue. The former were provided with stopcocks for adjusting the quantity of gas, and the latter with valves or dampers for adjusting the quantity of air.

The gas was burned at the bottom of the flues at B, B (fig. 40), the heat and products of combustion ascended the heating flue and were gathered into the chimney by the flue R. The oven was charged from the top at S by means of a gas-tight lid, which was afterwards fastened down, the gases escaping by means of an ascension pipe shown in dotted lines at S. The coke when finished was withdrawn from the bottom of the oven by means of the door E, which was worked by a screw and lever, which tipped it up so that the coke fell out by its own weight, down the slope, T, into the waggon beneath.

The charge was coked for 40 hours and first-class hard coke was made, the pieces were not so large as from ordinary coking coal, but the coke produced was very dense, sonorous, and hard.

The theoretical principle actuating the design of this oven was to gain high temperature, together with pressure, during coking. The high temperature attainable exceeded by far that possible in any other form of coke oven, and was only rendered possible by the formation and the design of the oven.

Built in a circular form, in single units, the oven was bound on the outside by iron bands every two or three feet in height, by which means, after the oven had arrived at its maximum expansion in working order, the iron bands were fixed and tightened, thus binding all the brickwork together. The outside walls were kept cool by the currents of cold air continually flowing through the air-recuperative flues. The air entered the outside walls at K (fig. 40) and ascended the wall, then it turned over and descended until it joined the combustion flue at B, where the hot air and gas were ignited and burned up the flue M; the air attained a very high temperature in its descent at the back of the heating flue M, so that a very high temperature was maintained in the combustion flue.

So evenly was the temperature in this oven regulated and so easily was the oven managed that, when looking into the empty oven after the coke had been discharged, it was impossible to see by the colour of the interior any difference in temperature between one part of the oven and another, the same high temperature being universal in all parts of it except the top.

The author then had a 5-ton waggon of coal slack sent from the colliery of Messrs. Pease & Partners, Durham, for the purpose of a comparative trial of this oven's capabilities, as against the horizontal type, and this, superintended by Dr. W. Carrick Anderson, in whose hands the trial was then put, was carried through, with the result that more coke was produced from a given quantity of this coal by about 5 per cent. than was possible from the same coal when employing horizontal by-product ovens. Dr. Anderson's report on these trials will be found in Chapter IX. in describing vertical coke ovens.

This new coking process, by means of high temperature and pressure, proved a perfect success in coking the problematical coal it was designed for, and, besides this achievement, it possessed features and gave results which were quite new in the carbonisation of coal.

The coke produced was of the highest quality, in large pieces, and, what was most astonishing, the pieces obtained were exactly half the diameter of the oven after allowing for the shrinkage against the walls. But, unlike the horizontal ovens above alluded to, *there was no hollow space in the centre.* The coke was cracked horizontally into pieces extending from the outside circumference to the centre, and could not be distinguished from the coke produced

by the Beehive process, except when the end that had been coked against the wall of the oven was examined, which showed the characteristic cauliflower head. This was the only distinguishing difference, but when a sample was weighed it proved very much heavier than Beehive or any other coke.

These characteristics are consistent with the conditions prevailing, under which carbonisation is conducted in this new oven. The coal is thrown in from the top from a waggon and, as it has a good drop, it requires no stamping down to consolidate it, except on the top.

The charging is done very expeditiously, as also the discharging. The coking process, after the charging is completed, proceeds regularly under an equable temperature above the ordinary (that is, the working temperature of a horizontal oven), because there is no danger of disintegration in this oven by high temperature, since it is bound on the outside, and like an arch, constructed with arch bricks, with small bulk of brickwork, in a single unit of one oven, whereas in the block of 30 or 60 horizontal ovens, with a stretch of roof of over 30 feet from back to front and the roof supported upon walls at a high temperature, it would be exceedingly risky, and, in fact, extremely difficult to work an oven of this class at a high temperature, not only on account of structural responsibilities, but also on account of the overheating of the upper parts where the gas accumulates, thus incurring the risk of injuring the gas for treatment for by-products.

In the vertical oven of this type these structural risks are nil, and the overheating of the gases is made impossible, because the gaseous accumulation towards the exit of this oven is at the top, which is comparatively cool, while the gas is protected in its way up to the top by the column of cold coal, in the centre of which it makes its exit, as will be subsequently explained.

As mentioned above, it proved successful in coking the Lanarkshire coal, and it is perhaps owing to the fact that the oven was 30 feet in height, and the coal thrown in from the top, that the occluded air was to a large extent driven out from between the particles of coal, for when coal is packed loosely into an oven, the air not only oxidises the coal, but keeps it apart and free from agglomeration, while in the case of the difficult coking coal of the Lanarkshire coalfield with its high gaseous content (about 50 per cent.) its oxygen is high, and at the coking period, when the temperature reaches it, at that moment the oxygen and hydrogen gases are set free, they take fire and burn, and in doing so consume the tarry matter that acts as the binder between the particles of coal, and, forming a fine microscopical ash in its place, prevents them combining into a solid massive coke, and leaves the particles practically of the same size as when charged. The two gases forming water vapour also play a part in preventing coherence.

When, however, this coal is subjected to the process in this high vertical oven, of a capacity comparative to that of an ordinary horizontal oven, say 5 tons' charge, and a diameter a little over 3 feet, the weight of the charge itself prevents expansion upwards, and the tightly bound circular walls exert an equal pressure all round, thus preventing any lateral expansion. The first stage of the carbonisation is the critical stage in the coke formation. The coking operation is carried on under a very high pressure and high temperature, and just at the moment when the crisis arrives for the expulsion of the gases (which under other circumstances would form large bubbles and when distended would disintegrate) in the tall, circular oven, is forced into the centre of the cold coal, from every side, the heat forming a thin vertical caisson or cylinder of melted coal, shown at C, C (figs. 40, 41), with a similar

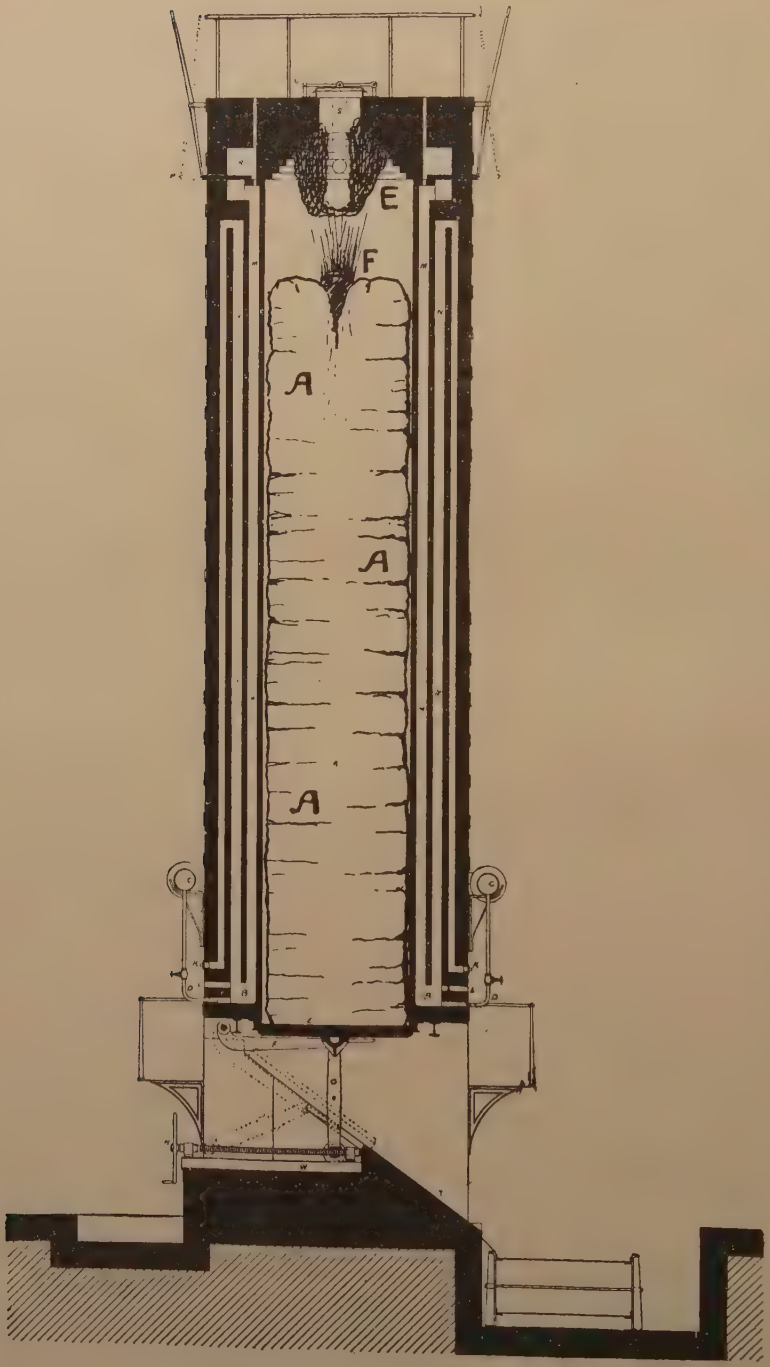


Fig. 42.—Vertical Section of Coke in Vertical Oven.

caisson of coked coal against the wall, as shown at A, A, the former acting as a gas-proof curtain at C, against the egress of any hydrocarbon gas passing towards the walls through A. The exit of these gases being thus barred, the only means of escape is up through the centre of the mass of comparatively cold coal, as at B, and as this is tightly pressed, the gas is very well cleaned from its heavy, tarry hydrocarbons before the top of the column of coal is reached, and the only gas that escapes through the coke towards the walls of the oven is hydrogen. These tarry bodies are condensed and held by the coal and ultimately coked; by this means the very heavy yield of coke in this oven is accounted for, while the yield of tar is very small and in the form of heavy oil.

In the ordinary horizontal oven the coke made near the wall is the hardest and best, because it has been subjected to the longest time in the oven as coke and exposed to the highest temperature, while the interior coke is softer. The same might be expected from the vertical oven, but this is not the case, although the coke in the vertical circular oven is exposed against the walls to the highest temperature prevailing in any part of the oven, and the better

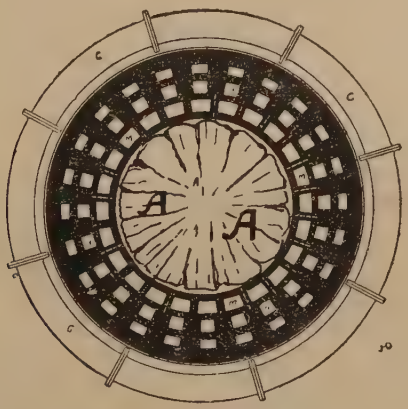


Fig. 43.—Horizontal Section of Coke in Vertical Oven.

and harder quality of coke would naturally be formed there. There is a compensating factor, however, working in the central part of this oven, by the condensation of the tarry bodies abstracted from the gas, in its passage up through this part of the charges. This condensed tar agglomerates the coal particles together at the end of the first period of carbonisation, forming a very pure, hard coke, free from ash, which fills up the central part of the charge quite solid (see figs. 42 and 43), no cavity whatever being observable when the coke is discharged, as is the case in the horizontal ovens. Fig. 44 shows the photograph of a piece of coke from this oven, which was 3 feet in diameter, the piece of coke being slightly less, by about 1 inch, than half the diameter of the oven, and terminating in a sharp point in the centre, which is the dividing line of the coke. When contracting from the circumference to the centre, it divides up into sections, like the several sections of an orange (see fig. 43 at A, A). The accumulation of tarry matter, as above stated, fills up, towards the final stage of carbonisation, the entire central portion, so much so that the gas that now finds its way through this liquid tar, coming up from the lower portions of the oven with some force, carrying up with it some of the liquid tar far

Fig. 44.—Large Piece of Coke from "Vertical Circular" Coke Oven.

above the surface of the top face of the coal, and, dashing it against the charging door and the arched roof, forms a piece of coke sponge, as shown in the photograph in fig. 45. These coke sponges are extremely light and very porous, the pores or cells attaining a size very similar to those of a very coarse sponge, some of them measuring about $\frac{3}{4}$ to 1 inch in diameter. This sponge is pure tar coke, and is quite distinct from the coke made from the coal. It has not been formed all at once, nor has it been confined or subjected to the least pressure, but appears to have been formed by the accretion of the constant splashing upward of the tar at F, in the centre of the charge, toward the end of the coking

Fig. 45.—Coke Sponge.

operation, and forming a large pendant stalactite of coke sponge on the roof at E, fig. 42.

The high temperature at which this oven can be worked makes it a convenient one for coking coals requiring a high temperature, as well as pressure, during the period of carbonisation, and as the regulation of temperature is extremely well arranged, any kind of coal can be coked to the best advantage in it.

In some ovens high temperature working proves not only fatal to the oven structure, but to the splitting up of the gases evolved by contact with the

hot walls. In this oven, as has been shown, the passage of the evolved gases is up the cool centre of the coal, where they deposit their heavy tarry bodies, and on reaching the upper part of the oven are cooled by cold coal through which they have passed, and, as the upper part of this oven is not heated, the roof is comparatively cool, so that no effect of a deleterious nature is made upon the gases as they pass away to the condensers. By this means the full amount of ammonia and benzol may be easily obtained from a given quantity of coal, although produced at a high temperature, with the resultant high yield and superior quality of coke produced.

These ovens can be constructed up to 40 inches in diameter, with a coking period of 48 hours, which, under the high temperature and pressure, makes coke equal to Beehive coke in quality and even superior in density.

The **"Appolt" Coke Oven** was one of the first vertical ovens constructed for carbonising coal, and was made as shown in fig. 46 with a series of vertical cells (*a*) of rectangular shape in horizontal section. Since these ovens were heated by the gases as they made their exit through apertures in the walls into the heating flues (*b*), no attempt was made to extract the by-products from them, nor could this have been very successfully accomplished with such a construction.

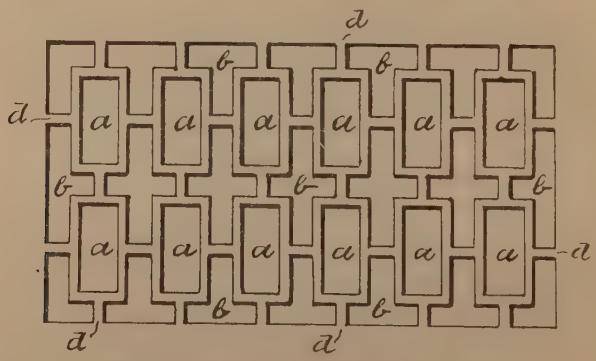


Fig. 46.—Plan of "Appolt" Coke Oven.

The extreme difficulty of efficiently binding the brickwork of a vertical rectangular oven constructed with vertical coking chambers grouped together makes the extraction of the gases extremely difficult. The constructional difficulties on this class of oven to ensure its being gas-tight under working operations are enormous.

The experience of the author, who constructed a similar oven for the manufacture of gas coke with recovery of by-products near London some years ago, sufficiently proved the futility of their construction, for the following reasons:—The oven in question required an abnormal amount of outside ironwork to keep it together, and it was never perfectly gas-tight. The structural difficulty with large internal spaces, depending solely on the strength of a thin firebrick lining to support them when the cell or chamber was empty, gave rise to strains in the interior brickwork, developing cracks which could not be easily repaired, and through which the gas was lost, due to the expansion of the brickwork during the heating-up and working, and the resistance of the outside bracing caused the cell walls to bulge.

It was in consideration of these structural and working difficulties associated with this experimental full-sized oven, 30 feet in height, that the author was led

to abandon the multi-cell design, as shown in fig. 47, for the **uni-cell vertical-circular** design, when called upon to design the coke oven for the Coltness Iron Company, described above, with its successful solution of more than one problem (structural) and successful working.

That good coke can be made in the multi-cellular oven, and also in the vertical oven designed by Jones, is a fact, but the difficulties attending the construction of rectangular chambers for the purpose of economical and perfect working are very great. Other ovens of the chamber type of low altitude and arranged around a centre have been built, but their cost and the above-named difficulties of binding such tall, huge masses of incandescent brickwork have led to their abandonment.

The author has proved, by practical experimental construction of vertical coking ovens, that if these are to be economically successful in producing first-class coke, saving all the by-products, and with the possibility of constructing them at as cheap or even less cost than the horizontal type of ovens, they should be constructed not less than 30 feet as the internal height of the coking

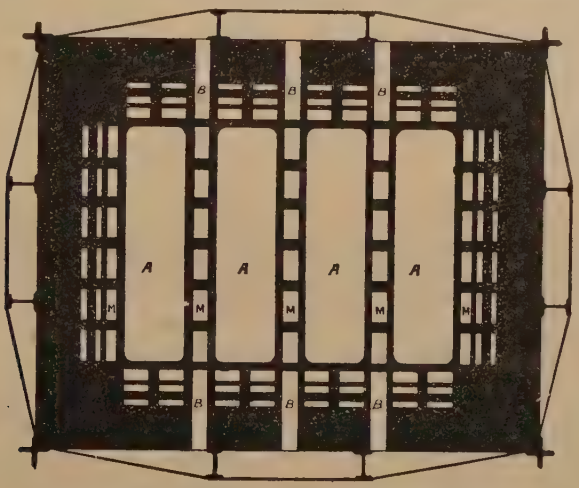


Fig. 47.—"Armstrong" Square Vertical Oven.

chamber, and from 36 to 40 inches in internal diameter, but not more, because every additional inch beyond 36 inches in diameter requires an *increasingly longer period* of carbonisation, and, therefore, becomes unprofitable.

A vertical circular oven of 30 feet internal height and 42 inches internal diameter seems to be the safe limit for economical working for most classes of coal.

These high, vertical circular ovens, saving all the by-products and producing the best hard coke, with as much as 15 per cent. higher yield than with the bee-hive oven, should prove the solution of the problem of coking the high fat coals that swell up so much as to preclude their being coked in the ordinary horizontal by-product oven, and are to this day coked by the wasteful process of the round or bee-hive oven.

These high fat coals, having a high content of volatile constituents (30 per cent. and upwards) with an excess of oxygen, swell up to such an extent as to enter the gas outlet pipes in the roof of the horizontal ovens. The gas, evolved

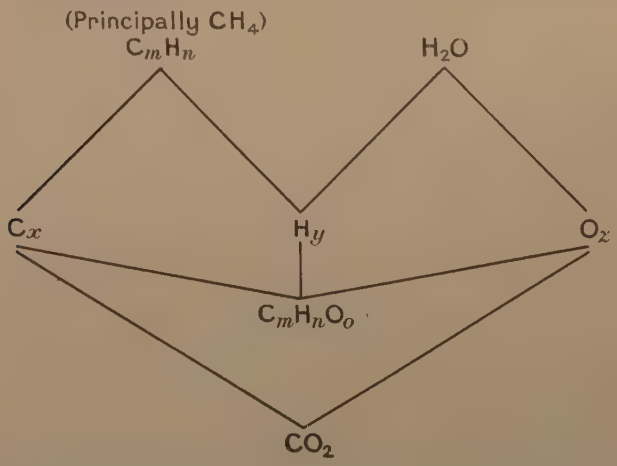
in great bulk, exerts a considerable pressure on the coal, which does not melt into a condition liquid enough to liberate it freely. Large bubbles of gas are therefore formed, with stiff walls, difficult to expand and burst, and derangement is caused in the conduct of the carbonising process. In the vertical oven, like the round bee-hive type, this class of coal can be allowed to expand, without doing any damage, by working the charge a little lower than for the ordinary coking coal, so that room is left above for upward expansion, while the pressure exerted on this class of coal during the coking period will tend to consolidate the inflated mass of stiff, cellular structure, and make the resultant coke more compact than it could otherwise have been by the horizontal oven process.

In the coking process, gas begins to be given off at a temperature as low as about 100° C., but scantily at first and combined with water vapour from the moisture in the coal. As the heat penetrates the coal mass the evolution of gas is more plentiful, and the gases that are evolved at the lower temperature are quite distinct from those at a higher temperature, the result of practical decomposition of the coal. The former, according to Professor Bedson, have an average composition of :—

	C. Cs.		Per cent. by volume.*
Carbon dioxide, ...	7·02	=	4·36
Oxygen, ...	4·53	=	2·81
Methane, ...	114·50	=	71·17
Ethane, ...	10·65	=	6·62
Nitrogen, ...	24·20	=	15·04
	160·90		100·00

These gases are generally regarded as consisting of the occluded gases of the coal, but when the decomposition of the coal commences, at a temperature approximating to 400° C. and upwards, the production of gas is rapid, and the hydrogen, taking up carbon, forms hydrocarbons, such as Marsh gas (CH_4), with much liquid tarry matter.

The following is a chemical scheme by Dr. W. C. Anderson illustrating the **reactions of the coking process :—**



* " Chemistry of Coke," by Dr. W. C. Anderson.

He also states (and the author agrees) that more information is still necessary regarding the nature of the reactions taking place during the carbonisation of coal to enable one to form definite opinions, and as long as the composition of the coal remains unknown, the reactions due to the coking process must remain in obscurity. The stable compounds which constitute the coal remain unaltered as long as it is in the earth unmined, but they are to a certain extent altered by their new environment when mined and brought to the surface, for the pressure of the superincumbent mass overlaying the coal deposit having been removed, there is free access of atmospheric air, and a veritable oxidation commences at ordinary temperatures.

In the coke oven this change is greatly accelerated when the temperature rises, so that the coal is fused into a pasty condition, and the several organic compounds, being dissociated, form new groups of compounds in the form of permanent gases which are stable at higher temperatures, and they are of more varied composition.

The following list gives the **compounds formed during the destructive distillation of coal,** according to the classification adopted in Wagner's "Chemical Technology" (13th German Edition, 1889).*

I. Coke.

II. Illuminating Gas:

(1) Illuminants or light givers:

(*a*) Gases:

Acetylene,	C_2H_2
Ethylene,	C_2H_4
Propylene,	C_3H_6
Butylene,	C_4H_8
Allylene,	C_3H_4
Crotonylene,	C_4H_6
Valerylene,	C_5H_8

(*b*) Vapours:

Benzene,	C_6H_6
Thiophene,	C_4H_4S
Styrene,	C_8H_8
Naphthalene,	$C_{10}H_8$
Methyl naphthalene,	$C_{11}H_{10}$
Fluorene,	$C_{13}H_{10}$
Fluoranthene,	$C_{15}H_{10}$
Propane,	C_3H_8
Butane,	C_4H_{10}

(2) Diluents or light supporters:

Hydrogen,	H_2
Methane,	CH_4
Carbonic oxide,	CO

(3) Impurities:

Carbonic acid,	CO_2
Ammonia,	NH_3
Cyanogen,	$(CN)_2$
Methyl cyanide,	CH_3CN
Sulphocyanogen,	CNS
Sulphuretted hydrogen,	H_2S
Sulphuretted hydrocarbons, Carbon disulphide,	CS_2
Carbon oxysulphide,	COS (probably).
Nitrogen,	N_2

* Quoted by Dr. Anderson in his "Chemistry of Coke," p. 65.

III. Ammonia liquor:

(1) Chief constituents:

Ammonium carbonate,	$(NH_4)_2 CO_3$
Ammonium sulphide,	$(NH_4)_2 S$

(2) Secondary constituents:

Ammonium sulphocyanide,	$NH_4 CNS$
Ammonium chloride,	NH_4Cl
Ammonium cyanide,	$NH_4 CN$

IV. Tar (according to Schulz and others):

(1) Neutral Compounds:

(*a*) Hydrocarbons:

(*α*) Fatty series:

		M.P.	B.P.
Crotonylene,	$C_4 H_6$	Liquid.	25° C.
Amylene,	$C_5 H_{10}$	,,	30° C.
Hexylene,	$C_6 H_{12}$	,,	71° C.
Hydrocarbon,	$C_6 H_{10}$	,,	85° C.
O. Jacobsen's hydrocarbon,	..	,,	159° C.
Paraffin,	..	Solid.	about 400° C.

(*β*) Aromatic series:

Benzene,	$C_6 H_6$	+ 3° C.	81° C.
Toluene,	$C_7 H_8$	Liquid.	111° C.
Ortho-xylene,	$C_8 H_{10}$	,,	141° C.
Meta-xylene,	$C_8 H_{10}$	,,	141° C.
Para-xylene,	$C_8 H_{10}$	15° C.	137° C.
Styrene,	$C_8 H_8$	Liquid.	146° C.
Mesitylene,	$C_9 H_{12}$	,,	163° C.
Pseudo-cumene,	$C_9 H_{12}$	,,	169° C.
Hemellithene,	$C_9 H_{12}$	,,	175° C.
Terpene,	$C_{10} H_{16}$	,,	171° C.
Cymene,	$C_{10} H_{14}$	,,	175° C.
Tetramethyl benzene,	$C_{10} H_{14}$	,,	..
Naphthalene dihydride,	$C_{10} H_{10}$	,,	205° C.
Naphthalene,	$C_{10} H_8$	80° C.	217° C.
α-Methyl naphthalene,	$C_{11} H_{10}$	Liquid.	243° C.
β-Methyl naphthalene,	$C_{11} H_{10}$	32·5° C.	241·5° C.
Diphenyl,	$C_{12} H_{10}$	71° C.	254° C.
Berthelot's hydrocarbon,	..	85° C.	260° C.
Acenaphthene,	$C_{12} H_{10}$	99° C.	280° C.
Fluorene,	$C_{13} H_{10}$	113° C.	294° C.
Phenanthrene,	$C_{14} H_{10}$	100° C.	340° C.
Fluoranthene,	$C_{15} H_{10}$	109° C.	above 360° C.
Pseudo-phenanthrene,	$C_{16} H_{12}$	115° C.	above 360° C.
Anthracene,	$C_{14} H_{10}$	213° C.	above 360° C.
Methyl anthracene,	$C_{15} H_{12}$	200° C.	above 360° C.
Pyrene,	$C_{16} H_{10}$	119° C.	above 360° C.
Chrysene,	$C_{18} H_{12}$	250° C.	above 360° C.
Chrysogen,	..	290° C.	above 360° C.
Para-chrysene,	..	320° C.	above 360° C.

(*b*) Other neutral compounds present in coal tar:

Carbon disulphide,	$C S_2$	Liquid.	47° C.
Ethyl alcohol,	C_2H_6O	,,	78° C.
Acetonitrile,	$C H_3 CN$	,,	82° C.
Water,	H_2O	,,	100° C.
Carbazole,	$C_{12} H_9 N$	238° C.	355° C.
Phenylnaphthyl carbazole,	$C_{16} H_{11} N$	330° C.	above 440° C.
Thiophene,	C_4H_4S	..	84° C.
Thioxene,	C_6H_8S	Liquid.	137° C.

(2) Acids :

Sulphuretted hydrogen,	H_2S	Gas.	..
Hydrocyanic acid,	HCN	,,	..
Carbonic acid,	CO_2	,,	..
Acetic acid,	$C_2H_4O_2$	17° C.	119° C.
Phenol,	C_6H_6O	42° C.	182° C.
Ortho-cresol,	C_7H_8O	31° C.	188° C.
Meta-cresol,	C_7H_8O	Liquid.	201° C.
Para-cresol,	C_7H_8O	36° C.	199° C.
Xylenol,	$C_8H_{10}O$	Liquid.	..
*l-Iso*durol,	$C_{10}H_{12}O_2$	215° C.	..
a-Pyro-cresol,	$C_{28}H_{26}O_2$	Liquid.	195° C.
β-Pyro-cresol,	$C_{28}H_{26}O_2$	,,	124° C.
γ-Pyro-cresol,	$C_{28}H_{26}O_2$	,,	104° C.
Benzoic acid,	$C_7H_6O_2$	121° C.	249° C.

(3) Bases :

Ammonia,	NH_3	Gas.	..
Pyridine,	C_5H_5N	Liquid.	115° C.
Pyrrole,	C_4H_5N	,,	126° C.
a-Picoline,	C_6H_7N	,,	134° C.
Lutidine,	C_7H_9N	,,	154° C.
Collidine,	$C_8H_{11}N$	,,	179° C.
Aniline,	C_6H_7N	,,	182° C.
Parvoline,	$C_9H_{13}N$	,,	188° C.
Corindine,	$C_{10}H_{15}N$	,,	211° C.
Rubidine,	$C_{11}H_{17}N$	,,	230° C.
Quinoline,	C_9H_7N	,,	236° C.
Quinaldine,	$C_{10}H_9N$	,,	246° C.
Viridine,	$C_{12}H_{19}N$	,,	251° C.
Lepidine,	$C_{10}H_9N$	,,	257° C.
Cryptidine,	$C_{11}H_{11}N$	,,	274° C.
Acridine,	$C_{13}H_9N$	107° C.	above 360° C.

(4) Asphalt-forming constituents ; Empyreumatic resins ; Carbon.

The complicated hydrocarbons in this list are derived from the coal in the process of carbonisation, and it is difficult to ascertain how they are combined in the coal. Probably it is in a simple form, the fact being that the hydrocarbons which are given off from the coal at a comparative low temperature, under 600° C., begin, above this temperature, to decompose and form new combinations. Carbon is expelled as the temperature rises ($C_2H_4 = C + CH_4$). Again, this heavy hydrocarbon C_2H_4 may be further broken up ($C_2H_4 = C_2 + 2H_2$), with a further elimination of hydrogen and deposition of carbon. As shown previously, this heavy hydrocarbon carrying with it its tarry matter in suspension deposits it in the surrounding cool coal, after which it makes its way up into the hotter regions, where a further loss of carbon is effected by deposition on the sides of the fissures and cracks in the coke through which the gas passes on its way out of the oven.

In all the processes carried on for carbonising coal and producing coke, the gaseous elements are never completely eliminated, the temperature never being high enough or the time long enough to fix entirely and separate the carbon, and too long coking at a high temperature should not be allowed, because, after the period of carbonisation marked by the evolution of flaming gases, the coke is in a state of incandescence, and any further loss of its gaseous elements will be at the expense of a further loss of carbon, since the gases now given off at a high temperature have a great affinity for carbon ; they carry away with them carbon, as they are expelled, in a very stable condition, which is not further deposited.

If atmospheric air is admitted by any means at this stage, a further loss in carbon occurs, as $C + O = CO$; or even this may happen, $C + 2OO = CO_2$, neither of which gases deposits carbon, but carries it away in the form of permanent gas.

If water vapour (steam) is admitted into the oven as in cooling the coke in the Beehive or round oven, the following reaction occurs with the incandescent coke :—$H_2O + C = H_2 + CO$ and $2H_2O + C = 2H_2 + CO_2$, forming permanent gases, from which carbon is not deposited, the hydrogen being set free, carbonic oxide and carbonic acid gases being formed, with positive loss of carbon.

Table showing the Composition in Volume per cent. of the Gases produced by the Action of Steam on Incandescent Coke.*

	I.	II.
Hydrogen,	54·52	56·90
Marsh Gas,	1·62	
Carbonic Oxide,	31·86	29·30
Carbonic Acid,	12·00	13·80
	100·00	100·00

I. The coke operated upon had been previously heated in a platinum crucible to expel any volatile matter. The composition was found by explosion with oxygen in an eudiometer. The analysis was made by Langlois.

II. The coke used was from Derbyshire coal and the analysis was made by Frankland.

The proposition to treat the incandescent coke, when finished in the oven, by passing steam through it, for the purpose of desulphurising it, could only result in gasifying a large amount of the carbon without having much effect on the sulphur, as the reaction of steam on hot carbon is much more energetic and wasteful than any compensating reaction by the steam on the sulphur present in the coke, because the steam acts upon the exposed hot surface of the coke, decomposing it quickly, whereas the amount of sulphur that it is possible to act upon would also be on the same surface; the hard, impermeable nature of the coke cells prevents the entrance of steam into their interior, and, in fact, the steam is completely decomposed, almost instantaneously, when it comes in contact with the hot carbon. It is a mistake to be misled by the fact that steam passing through hot coke, containing sulphur, desulphurises the coke; it gives off offensive fumes of sulphuretted hydrogen, but an exceedingly small amount of sulphur will produce strongly smelling gases. It has also been proved that such a process of desulphurisation is not only incomplete but uneconomical.

If water is added to the coal slack when it is placed in the coke oven, it acts as a binder, not in the sense of forming or assisting to form a hard coke (the reaction would be the reverse at the coking temperature), but in the initial stage of charging the oven, a certain amount of moisture prevents dusting, and, by a peculiar action on the particles of coal, promotes solidification when pressure is used—that is, when dry coal is pressed into a vessel, the grains have a rolling or sliding action over each other, and the small interstices between them are not completely filled; they are more mobile, but when moisture is

* Quoted by Dr. Percy in his "Treatise on Metallurgy," p. 418.

added the grains cease to move over each other and the interstices are filled up, so that a larger charge can be inserted into a given space.

Any water thus added is generally dispelled long before the period of incandescence or red-hot coke is reached, so that it cannot have any effect on the bulk of the coke.

When a sample of coke from a Beehive or round oven is examined, it is surprising how small an amount of moisture is present in it, although such a large quantity of water was thrown upon the coke in the oven; but this can be explained by the enormous surface of the coke presented to the water, the very high temperature, and the thick crust of coke, converting the water into steam very rapidly, which passes off immediately, leaving the coke cooler and comparatively dry.

The **time occupied in the carbonisation of coal** varies according to the class of coal operated upon and the process adopted to effect it.

The old Beehive or round oven process occupied from 48 to 90 hours, and the modern horizontal ovens from 24 to 36 hours. Vertical ovens take from 36 to 48 hours or more, according to their width or diameter. The coking period is in all processes a gradual one, the process of heating the coal and melting it does not help the same development in the mass as in the heating and melting of materials which become liquid, because, as in the case of pitch, so soon as the first layer becomes heated against the side of the boiler or pan, it liquefies, and remains liquid, becoming, therefore, a better conductor of heat, and soon the whole contents of the boiler attain the same temperature and begin to circulate as a liquid.

In the coke oven, of whatever form, or for whatever process, the liquefaction or semi-liquefaction of the coal is practically little more than momentary; it has no sooner arrived at the temperature of its softening or melting stage than it commences to stiffen and solidify into hard coke; the progress of the coking operation is, therefore, a very slow one, and is progressive. In the line of heat through the coke to the centre of the oven there are no two points absolutely alike; that part of the charge nearest the hot walls will be melted, will stiffen and become hard, red-hot, incandescent coke, before the centre, is more than warm in the case of a large oven.

The time, therefore, for the actual carbonisation of coal is very short, provided the temperature is high, and depends upon the distance that the heat has to penetrate into the mass of coal to be coked.

The fact that the coking process is a progressive one led the builders of the horizontal ovens to adopt a very narrow coking chamber, in order to facilitate the penetration of the heat to the centre from both side walls of the charge, thus shortening the coking period and obtaining a larger output per oven per year than could be obtained if operating with ovens twice the width, the penetrating power of the heat diminishing in a rapid proportional ratio to the distance it has to travel.

Coke made in a vertical oven of 18 inches in diameter, in 12 to 18 hours, will not be so good as that made in an oven 36 inches in diameter in 40 hours, but the output will be greater, while the running charges are the same, and if the coke produced in the shorter time answers the same purpose as that which takes longer to make, it would be folly to carry out the process by the latter method.

Coke is required for various purposes, however, and while there is a market for coke of somewhat less hardness and of inferior quality, there is also a demand for coke of the highest quality and hardness, and, as has been stated

previously, the best coke requires time for its formation, together with a high temperature, and for the purpose of making this hard coke narrow ovens are useless. They could, of course, be used for the purpose, and hard coke made in them by keeping the coke after it was fully carbonised at a good temperature for a longer period, but such a procedure would be foolish and uneconomical.

Large ovens—that is, ovens where the heat has to penetrate through a good thickness of coal in order to carbonise it all through, taking at least 48 hours—would be most suited for the purpose of making the best and hardest coke, and such ovens would be the most economical, because the major portion of the coal is coked (in the circular vertical ovens) in the early stages of the process, and while the heat is penetrating to the central portion of the charge, the bulk would be undergoing the hardening process during the time occupied to coke the remainder in the interior.

The longer the coking period (up to a certain point) the nearer the coke approaches to a higher percentage of carbon with less volatile matter, and from observations made, it seems that this period under a high temperature is about 60 hours; beyond this period there is an appreciable loss of carbon, carried away by the gases, and it is quite consistent to suppose that when the coking process is finished, and the coke formed is shrinking away from the walls and doors of the oven, that unless a check is put upon the exit of the gases in order to form a pressure *inside* the oven, it is highly probable that atmospheric air will find admittance, as at this period all the luting round the doors is dry and shrunken. The fact that no smoke is seen coming through the cracks and chinks may lead to the supposition that the oven is air-tight, but this is highly improbable, and great care should be taken to see that the luting is attended to, because at this stage, when further heating is necessary to coke the interior remnant of coal, and in order to harden the coke, a considerable loss may occur in the yield of coke.

An essential quality in the coke produced is **uniformity,** and this can only be obtained by uniformity of the temperature applied to the coal in all parts of the oven during carbonisation. This has been one of the most difficult of all the problems that the coke manufacturer has had to solve, as the patent office records witness by the numerous inventions that have been devised to accomplish this end. In fact, the progress attained in the development of the process of carbonisation is mainly due to this investigation.

If a coke oven is not heated to the same temperature in all its parts, there is, as a result, a proportion of the charge undercoked, and, if an attempt is made to correct this deficiency by prolonged coking, losses occur to the economical working of the ovens.

In the early stages of the development of the horizontal oven, difficulties were encountered in directing the heat to every part of the walls equally, and some elaborate arrangements of flues and dampers, necessitating a great amount of labour, were adopted. The problem of heating a series of walls, forming the horizontal coking cells or chambers, 33 feet long by about 6 to 8 feet high, economically and equably, is not an easy matter, but several ways of doing so have been elaborated with more or less success.

The history and development of this important problem will be fully described in Chapters VI. and VII. To show how the unequal heating of horizontal ovens can derange the whole operation, the author cites the following case. While inspecting in Durham some ovens which were not working satisfactorily, it was found that, owing to some defect in the heating flues, the coking period was

prolonged over 80 hours before the charge was properly finished, although the ovens were only about 20 inches wide inside. When these ovens were discharged, large black or dull red patches were observable on the walls; in fact, the walls were all temperatures from 500° C. up to 1,100° C. in different localities. With such heating, proper coking is impossible. When difficulties occur such as above described, a temptation to force the temperature is often exercised in order to expedite the operation, with the inevitable destruction of the flues.

In the designing and construction of a coke oven this aspect of the question must not be lost sight of, and the heating arrangements must be made so that the entire chamber walls may attain, and retain during the period of carbonisation, the same temperature, within reasonable limits. This has to some extent been accomplished in certain classes of ovens, but not universally. In the round or Beehive oven, the working temperature is practically the same over the top of the charge in a well-designed oven, and worked by a skilled operator who knows how to adjust the admittance of air to the oven.

In vertical ovens that are circular on plan, a perfectly equable temperature is easily obtained and maintained throughout the coking period, and when such an oven has been discharged, and the interior is examined, from the charging door at the top, the colour of the entire walls from the bottom to the top and all round is of the same pale yellow tint, indicating a very uniform temperature; and to this fact may be ascribed one of the reasons of its success. The gas and air in this oven are very easily adjusted and controlled; when the author saw one of this design working at Coltness Iron Works, it was heated by blast-furnace gas obtained from the adjoining blast furnaces, and by the recuperative arrangements that were adopted in the walls of the oven almost any temperature could be produced as desired.

This uniformity of temperature resulted in the production of the highest grade coke, without soft pieces, except about the centre of the top of the coke in the ovens, where the tar had accumulated, and where the gases by escaping through it while semi-liquid had blown it up into a sponge about 12 to 15 inches long by about 4 inches in diameter at the top end, tapering away at the bottom (see F, fig. 42). This piece of tar sponge proves the theoretical correctness of the reasoning in this and other chapters for the softening of the coal with the expulsion of gas, which is driven in front of the advance of the heat, through the coal charge, and towards the finish of the carbonisation, in the vertical circular oven the tar was driven by the gases and deposited in the coal as the coking progressed towards the centre. But as the temperature is never high enough in the coal in front of the soft zone to carbonise and coke the tar, except that which adheres to the coal, the excess of tar deposited by the process in this oven towards the finish is driven into the upper part of the centre of the charge, with the result stated above.

High-temperature coking—that is, above the average temperature—should only be resorted to when dealing with coal requiring it, since high temperature has the tendency to split up the coke transversely—that is, to produce short and small pieces. It seems that for a good ordinary coal in general practice a moderate temperature is the best to produce coke in large-sized pieces and of good quality.

Coke manufactured in horizontal or other ovens cannot be obtained, however, in pieces longer than half the width of the oven between the walls, and is usually much shorter, owing to the shrinkage of the coke when it is fully carbonised, except in the case of vertical circular ovens already referred to

above, where the reasons are given for this extra length. When the oven is not working uniformly—that is, where the heat is more advanced on one side of the oven than on the other—the period for formation of the coke on the hotter side will be the longer. The dividing line between the extreme limits of the two opposite heat forces, as they progress from the two sides towards the centre of the oven, is the mean (see fig. 48). If the heating, therefore, is uniform, this dividing line, D H, will be in the centre, but if not uniform it will be nearer to the cooler side. Largest or longest coke is obtained from the round or Beehive oven, since the heat is only applied on one side—viz., the top of the charge—having no opposing heat force to divide the finished coke. Reference has been made already to the frothy central core at the top of the vertical oven. Something similar occurs in the horizontal type of oven, but apparently from another source; that part of the charge situated against the two end doors, where the heat is very low, produces very soft spongy coke, not from the excess of tar driven into this locality, as in the case of the vertical oven, but from the fact of having been carbonised at a very low temperature. This part of the

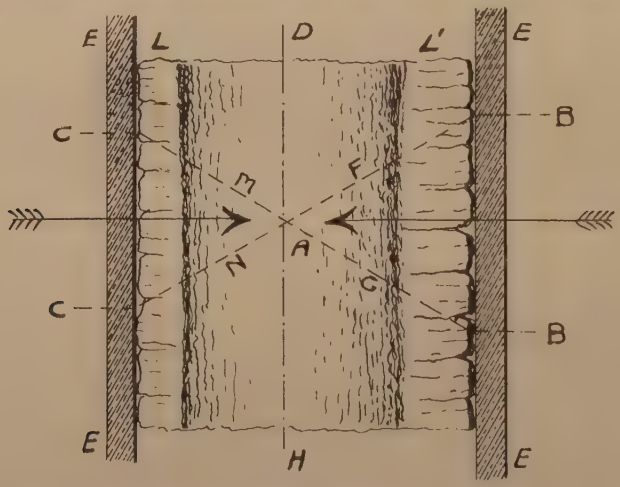


Fig. 48.—Diagram of the Theoretical Penetration of Heat in Coke Oven.

finished charge is termed "black ends," and has to be separated from the bulk of properly carbonised coke. As much as from 6 to 8 per cent. of this class of coke is made in horizontal by-product ovens.

In the Beehive ovens a certain amount of coke is also to be detached from that which is properly coked and classed as first rate, and this, with the ash that remains from the consumption of the coke during carbonisation, represents a very large percentage of the coals of the original charge. This inferior coke, by the fact of having been to a certain extent burned and mixed with ash and clinker, is practically useless and generally given away, but as this residue often contains a large amount of good fuel in small pieces, it ought to be washed, sorted, and the good fuel saved for briquette-making. This matter will be referred to again in the chapter dealing with the briquetting of fuel and the saving of waste

The **colour** of the coke produced used to be a guide to its quality, since Beehive coke of the first quality was generally of a light, steel grey with a shining

silvery appearance, but the same quality of coke, in fact, the same coke, could be rendered black and dirty simply by cooling it with access of air and with dirty water. But, on the other hand, coke produced by other methods, not having the quality of the last named, is extremely difficult to produce with this coveted colour.

The production of silver-coloured coke in the round or Beehive oven is very simply accomplished, since the coke is cooled inside the oven by means of water thrown into the oven on the top of the coke, the air being expelled by the solid bed of coke at the bottom of the oven, and also the presence of a large quantity of steam in the oven ensures for the period of cooling some pressure in the oven excluding the air. Cooling under these circumstances with clean water is sure to produce the desired colour in the coke, provided the coal operated on has the requisite quality.

When coke is discharged from any other form of oven, and cooled outside the oven where the air has access, as occurs in the ordinary method of operation of the horizontal ovens, the coke is generally dull or black in colour; but when these ovens are discharged into a cooling box where the air is excluded and clean water used, the coke can be produced with a better colour.

With regard to the shrinkage of coke in bulk, by cooling with water, there is a great diversity of opinion. There must be a diminution to some extent of bulk in cooling, first by reason of the contraction that must take place due to the reaction between the water or steam and the hot coke, forming CO gas, which is lost: $3C + 4H_2O = 4H_2 + 2CO + CO_2$. And secondly, is coke absolutely permanent in size at all temperatures?

Probably a great deal will depend upon the purity of the coke and its freedom from ash.

In any case, the amount of shrinkage is not very great, and in some classes of coke may not be perceptible, but such shrinkage cannot to any extent affect the quality or subsequent use of the coke for any purpose to which it may be applied.

The **quenching of coke** is a matter that calls for a little attention to the details of having the water clean and, if possible, quenching out of contact with air; also that the proper quantity of water, and no more, is used, so that there will not be more than, say, 3 to 4 per cent. of moisture retained in the coke.

An excess of moisture depreciates the value of coke as a fuel, since the moisture has to be driven off as steam by the heat of the furnace before the carbon in the coke can be ignited, and since the steam in escaping may pass over incandescent carbon in the furnace, the reaction of $H_2O + C = H_2 + CO$ may occur and result in a further loss of fuel as carbon monoxide, which may be carried away and wasted owing to there being insufficient heat to ignite it.

It is, therefore, essential when using coke as a fuel, to see that it is as dry as possible, and when purchasing it to have the water content ascertained.

Perfectly dry coke will not absorb (according to M. de Marsilly) more than from 1 to 2·5 per cent. of water when exposed to an atmosphere saturated with moisture at the ordinary temperature, but it will absorb in 24 hours' immersion as much as 51 per cent. of its weight of water.

Coke produced from coal containing a large amount of sulphur is prohibitive in many departments of industry, and it is generally useless to attempt to desulphurise it after it has been made. Such coke can be used as fuel for ordinary purposes where its sulphur content will have no deleterious effects, but coke for metallurgical purposes should be as pure as possible, and free from both sulphur and phosphorus. When metallurgical coke is the object of manufacture, it is essential to choose the right class of coal, and to eliminate

as far as possible the deleterious ingredients it may contain, previous to its carbonisation. Any subsequent treatment is useless.

By washing and screening coal intended for metallurgical coke manufacture, a very pure and useful coke can be produced, and in the working of certain seams of coal, these preliminary processes are now absolutely necessary to produce the high quality of coke that is required. This has developed into a highly scientific industry (see Chapter V.).

LOW TEMPERATURE CARBONISATION.

A great deal of scientific thought and attention has been given recently to low temperature coking—that is, carbonisation at a temperature under 600° C. This has not been primarily for the manufacture of coke, but, as in the case of gas manufacture, coke is a residue in these processes. Practically, the process of carbonisation is the same, but the results obtained at low and high temperatures are entirely different. The process is slower at the low than at the high temperature, but the action of the heat on the coal is the same—that is to say, the coal is carbonised, but to a less extent, by the former process. The same phenomena are observed in the case of the low temperature method as have been described for the high temperature method. When, however, it is considered that the material operated upon is of such a complex nature, that when heat is applied it begins to disintegrate, and this is governed by the amount of heat applied, it will be seen that the result is by no means the same. The residue that remains after, say, 4½ hours' coking at from 400° to 600° C. is porous and soft, and contains a considerable amount of volatile matter, which appears to be permanent in the coal at this low temperature. If a higher temperature is reached, then this is eliminated also, and a coke produced containing little volatile matter. The two methods of carbonisation are similar in that the heat melts the coal as it progresses inwards, forming an amorphous mass and liberating the gas, which, if not confined or under pressure, will form a very soft, light, spongy residue or coke, while, if conducted under pressure and confined, it will to all intents and purposes behave in a similar manner to coke produced by a high temperature and form a dense coke, but without the metallic ring of hardness of that produced by the high temperature.

From a chemical and physical point of view the results of the two processes are almost diametrically opposite. The result of a high temperature carbonisation is hard, sonorous, dense coke, abundant gas, ammonia, and benzol, but little tar; whilst low temperature carbonisation gives only 50 per cent. of the gas, a very large quantity of tar and oil of quite a different nature from that produced by the former process, and little ammonia. But, apart from the oil, motor spirit is also obtained, as against the benzol of high temperature practice. Mr. F. D. Marshall* states:—"The expression 'low temperature' is purely a relative one as distinguished from the temperature employed at gas works and coke ovens for the treatment of coal to produce illuminating gas, metallurgical coke, etc. The temperatures which may be termed 'high,' employed by gas and coke-oven works, range from 2,000° to 2,200° F.

"To maintain this temperature for any length of time, retorts or chambers of fireclay or other refractory material are essential; these are very costly and their life is short. On the other hand, the temperature called 'low' ranges from 900° to 1,200° F. (an incipient red heat), and the retort employed is of cast iron. Six years of experience have proved these cast-iron retorts to be

* *Iron and Coal Trades Review*, Feb. 28th, 1919.

practically indestructible, and they are cheap to instal. The temperature difference in the two processes is, therefore, some 1,000° F.

"The results obtained, however, by submitting coal to destructive distillation or carbonisation by either of these widely differing temperatures are very notable. An average coal when submitted to a temperature in the retorts of some 2,000° to 2,200° F. will yield approximately per ton :—Gas, 12,000 to 13,000 cubic feet of approximately 500 B.T.U. ; coke residue, 66 per cent. ; tar, 9 to 10 gallons ; sulphate of ammonia, 20 to 28 lbs. A coal of similar character submitted to a temperature of 900° to 1,000° F. will yield per ton :—Gas, 4,000 to 6,000 cubic feet of approximately 650 B.T.U. ; coke, 70 to 75 per cent. ; tar oils, 18 to 22 gallons ; sulphate, 15 to 22 lbs. The study of the properties of low temperature coke residue is very interesting.

"High temperature gas coke is exceedingly dense, practically devoid of any volatile matter, making it difficult to burn in an open grate except with the assistance of a good draught. For this reason in normal times it has never been a popular domestic fuel in this country. On the Continent, however, for consumption in closed slow-combustion stoves it is eagerly sought after, hence the big export of coke from the British Isles to the Continent. The density of gasworks coke is not due to pressure, but to the prolonged heating at a very high temperature." A description of the low temperature process is given in another chapter, but a few results, taken from the same source as above, are given here. Mr. Marshall further states :—

"*Low Temperature Gas.*—The gas from ordinary bituminous coal varies in thermal value from 550 to 650 B.T.U., and is subjected to the process of 'stripping' by washing with an oil, preferably a middle distillate from low temperature tar. The 'stripping' produces gas of approximately 550 to 650 B.T.U. per cubic foot down to 400 to 450 B.T.U., and what is absorbed by the oil (which readily parts with it again on distillation) is in the *nature of a motor spirit*, a paraffinoid with a specific gravity of 0·760 to 0·800.

"On an average the gas 'stripping' yields spirits equivalent to $1\frac{1}{2}$ and 3 gallons per ton of coal carbonised. The stripped gas is used to heat the retorts, and any surplus can be sold to any neighbouring factory, as it is an excellent power and heating gas.

"*Low Temperature Tar Oils.*—The crude oils obtained by low temperature carbonisation of coal, cannel, or lignite, are hydrocarbons of the paraffin series, as distinguished from those derived from gasworks or coke-oven tars, the first distillate of which is benzene C_6H_6. Incidentally, 90 per cent. 'benzol' is really crude benzene, 90 per cent. of which distils below 100° C., and the balance up to 140° C. Benzene and its homologues are termed benzenoids, and are commercially derived from the high temperature gasworks and coke-oven tars. They have a most important function to perform in being the basis of nitrobenzol, used during the war in the manufacture of high explosives, and in times of peace as the basis of the aniline dye industry, and also to provide a good motor fuel (see fig. 49).

"In describing low temperature tar oils, Dr. Mollwo Perkins, a keen student of these oils, is probably right in terming them a half-way house between the products of natural petroleum and shale oils. But, however stable these low temperature oils may be as regards the action of acids, the gases which produce them are wonderfully susceptible to temperature variations during their evolution.

"It was of great interest to learn the temperature at which they lose the characteristics of olefine and pass over to the benzenoid series of aromatic hydrocarbons, and we are indebted to Dr. Dunstan, late of the East Ham

Technical College, for having contributed to this solution. During a series of trials at the waterworks he established pretty closely that the turning point was approximately 1,400° F., or the highest point the cast-iron retorts could comfortably stand. The trials were conducted at between 1,200° and 1,300° F., and in Dr. Dunstan's words :—' The present series of experiments were undertaken to increase the yield of the aromatic series, and this could only be done by raising the temperature of distillation, without, however, militating against the excellent nature of the residual smokeless fuel or coke, which is so important a factor in the process, but which Mr. Marshall and Mr. Tozer reported to me at the conclusion of my trials was of very good quality. The tar oils at between 1,200° F. and 1,300° F. were heavier than at a lower temperature, being (wet) tar 1·085 at 60° F., and (dry) tar at 1·10. The light oils given off by fractionation at 170° C. gave 19 per cent. of cresylic acid and 4·7 per cent. of a combination of benzol and toluol.' Therefore, it was clear that if we wished to stick

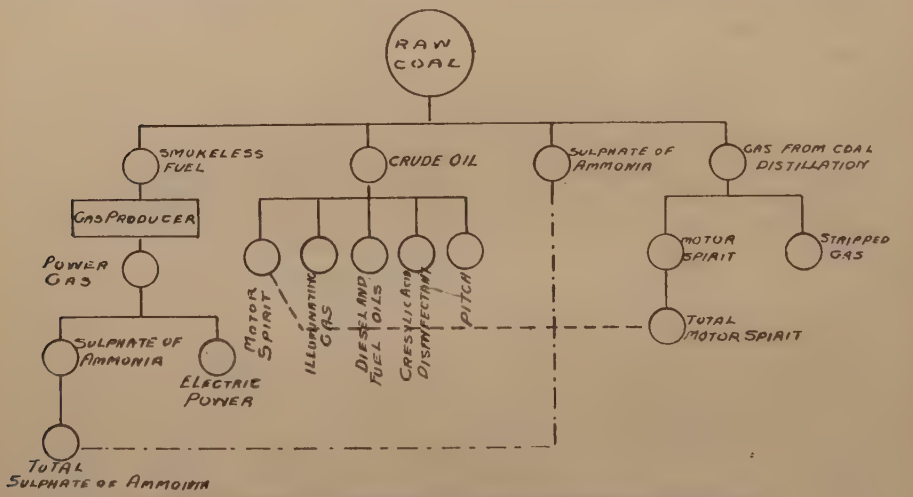


Fig. 49.—Diagram of Products of Low Temperature Carbonisation.

to the process of evolving unadulterated paraffins, yielding good motor spirit, etc., and a coke with a fair percentage of inflammable gases, it was necessary for us to keep below 1,200° F., and not to be tempted to wander into the realms of benzenes and benzenoids, which could only have ended in destroying our retorts, and at the best providing an oil of a hybrid character.

" But it was a most interesting experiment and of great value, and it leaves one wondering which kind of oils the Government (Ministry of Oil Productions) obtained from their war emergency scheme, in trying to combine the operations of ordinary high temperature vertical gasworks retorts for the purpose of obtaining oils and a large quantity of gas at the same time. The gas-making high temperature zone of the retort would produce benzenes and benzenoids, while the upper portion or low temperature zone would produce paraffins and paraffinoids, and as there were no means of separating the gases producing these widely differing classes of oils, it appears that they must have obtained a very mixed sample. It will now be interesting to set out what typical coals yield when submitted to low temperature carbonisation at some 1,000° F. and under, and some of the results of vastly varying but typical coals are appended :—

Some Results obtained by Low Temperature Carbonisation under 1,200° F.

Name of Coal.	Analysis.										Yield per Ton of Coal Carbonised.							
	Coal.					Tarless Fuel.					A. Spirit.	Light Oils.	Heavy Oils.	Total Oils,	Tar Acids, Cresylic.	Pit Pitch.	Sulphate.	Tarless Fuel.
	H_2O.	V.M.	F.C.	Ash.	N.	H_2O.	V.M.	F.C.	Ash.	N.								
											Galls.	Galls.	Galls.	Galls.	Galls.	Cwts.	Lbs.	Cwts.
Ballengleich (Natal),	3·34	25·10	53·65	19·0	..	3·7	9·85	63·11	23·34	..	3·25	3·9	4·0	15·2	1·8	0·34	30·5	16·0
Forest of Dean,	3·1	31·2	58·57	7·0	..	dry	12·9	78·4	8·7	..	2·0	5·7	5·4	15·2	..	..	13·0	15·9
Hulton,	dry	34·73	50·06	7·21	..	dry	8·26	82·85	8·89	..	0·83	4·9	7·9	18·4	..	..	20·7	14·7
Maltby Main,	13·0	29·2	..	8·9	..	..	..	..	11·0	..	4·50	5·7	4·7	16·3	..	..	9·5	14·5
Silkstone Beanshaw,	..	30·9	..	..	..	..	8·0	81·6	10·4	..	5·06	6·0	6·1	17·2	..	..	..	..
Silkstone Winter Slack,	dry	32·85	58·31	8·84	..	dry	7·71	82·3	9·99	..	0·4	4·4	10·5	19·8	..	..	12·1	15·5
Silkstone two-foot Slack,	dry	32·96	57·39	9·65	..	dry	8·08	75·52	16·4	..	0·5	5·0	11·0	22·0	..	..	10·91	15·75
Niddrie Cannel,	dry	50·87	44·4	4·73	..	..	..	..	..	..	5·0	12·0	19·0	..	..	2·37	17·4	10·0
Newbattle Cannel,	1·14	50·23	44·06	4·33	..	..	..	..	..	..	5·0	13·5	28·5	..	..	2·06	21·8	10·0
Sulphide Corporation (Australia),	2·08	31·8	55·9	8·43	1·75	..	10·3	75·4	18·26	1·95	5·37	..	8·0	16·4	..	0·67	19·8	15·5
Bignall Hill Washed Pearls,	..	..	..	5·4	..	..	..	..	7·4	..	2·5	5·7	4·0	22·0	..	0·8	23·8	14·0
Telmanston (Slack) Kent Coal,	..	..	..	..	..	..	..	..	12·5	..	2·5	6·0	4·5	20·3	..	63·5%	22	16·0
Snowdon Kent Coal,	..	..	..	..	..	..	..	..	13·8	..	3·0	8·0	3·9	17·3	..	62·0%	19·2	16·0
Stanton Iron and Coal Co. (Cannel),	..	..	..	..	..	..	..	..	..	..	7·6	7·92	11·88	44·0	3·08	..	25·33	10·0
Wigan (Cannel),	1·64	57·82	36·01	3·93	..	2·25	7·96	82·77	7·02	1·30	6·8	14·7	44·7	85·1	8·0	1·15	22·0	10·0
Lignite (Spanish),	5·24	35·74	..	9·99	1·30	..	12·50	15·60	..	1·24	2·2	4·4	6·95	22·71	..	..	18·5	11·0
Shale (Spanish),	..	..	..	..	..	..	..	..	..	..	1·1	1·2	17·00	30·1	..	..	19·1	..
Glapwell (Slack),	..	..	..	..	..	..	..	..	..	..	3·54	5·03	5·40	17·96	13·0	..	18·6	16·0
Glapwell Nuts,	..	..	..	..	..	..	..	..	..	..	4·39	10·17	8·39	28·69	..	..	10·2	15·5
Hucknell Belt Pickings,	3·8	21·2	43·7	31·0	..	..	..	..	3·4	..	2·2	7·52	2·27	14·2	..	9·39	11·0	14·4
Tyne Boghead Cannel (Mickley),	..	..	..	..	..	..	..	..	..	..	3·12	14·9	19·94	53·5	..	..	23·0	14·0

"*Note.*—In addition to the production of spirits (petrols) obtained from the fractionation of the tar oils, an additional 2 to 4 gallons per ton of coal carbonised will be obtained by "stripping" the rich gas, which must be added to that tabulated in this statement under Column A.

"*Cokes.*—The cokes contain from 7 per cent. to 12 per cent. of volatile matter.

"*Tar Oils.*—These fractionate into tar acids (cresols) and represent (approximately) 7 per cent. to 14 per cent. of the crude oils. The oils contain 5 per cent. to 8 per cent. of paraffin wax.

"To take, however, concrete instances of two widely different types, for an ordinary bituminous coal and a medium good cannel, the results were as follows :—

"*Bignall Hill Pearls.*

"Treated, 5 tons.

Coke = 75 per cent., containing 9 per cent. inflammable gas, very hard and dense.

Crude oils, water-free = 22·0 gallons per ton, specific gravity 1·060.

Fractions of crude oil :—

Ammoniacal liquor,	9·5 per cent.			
Oils, 170° C.,	6·9 „	= 1·33 gals.	0·800 Sp. Gr.	
170°-230° C.,	16·5 „	= 3·66 gals.	0·970	„
230°-270° C.,	9·0 „	= 1·99 gals.		
270°-350° C.,	36·0 „	= 7·99 gals.	1·04	„
Pitch, 23 per cent.				

Note.—The fraction 270° to 350° C., was pushed to the decomposition stage, and yielded a very fine lubricant.

Ash in coke, 10·3 per cent.

In addition, the oil from the 'stripping' plant yielded at 150° C. 2·61 gallons of motor spirit, making the total yield of spirits 3·94 gallons per ton.

"*Tyne Boghead Cannel (Mickley).*

"Treated, 5 tons.

Coke = 70 per cent., poor for domestic purposes (20·4 per cent. of ash), but good for 'producer gas.'

Crude oils = 53·5 gallons per ton.

Fractions of oils :—

Ammoniacal liquor,	0·5 per cent.			
Oils up to 170° C.,	8·0 „	= 4·24 gals.	0·780 Sp. Gr.	
170°-230° C.,	10·0 „	= 5·30 gals.	0·832	„
230°-270° C.,	13·0 „	= 6·89 gals.		
Over 270° C.,	38·0 „	= 21·14 gals.	0·886	„
Pitch, 29 per cent.				

"The stripping oil yielded up to 160° C., 4·5 gallons per ton, making the total yield of spirits per ton = 8·75 gallons. The specific gravity of the spirit from the stripping plant was 0·796. Ash in coke, 20·4 per cent.

" It will be noted that both the bituminous coal and cannel coal yielded on fractionation 23 per cent. and 29 per cent. of pitch respectively, less than half the quantity yielded by the fractionation of gas tars.

" The low temperature pitch is remarkable, too, on account of its plasticity and the low percentage of free carbon which it contains, and it has proved itself to be an excellent electric insulator, and superior for briquetting purposes.

" *Motor Spirit.*—The fraction up to 170° C., combined with the spirit obtained by stripping the gas, has a specific gravity on the average of 0·780 to 0·800, and has proved, by trials of 300 miles, to be a first-class motor spirit, fully equal to any motor spirit on the market. When properly rectified, it is a water-white spirit with an agreeable odour.

" *Middle Oils.*—The fractions from 170° to 230° are excellent fuel and illuminating oils, and of great value for internal combustion oil engines, *especially of the Diesel type,* as we have proved.

" *Heavy Oils.*—The heavy oils are good lubricants, and combined with the middle oils make good Diesel fuel ; in fact, it is scarcely necessary to separate the two for this purpose. Quoting Dr. Mollwo Perkin, he states that—'The spirit obtained has a specific gravity of about 0·800, and resembles very closely motor spirit obtained from petroleum. The middle oils have specific gravity of about 0·900, and a flash point of 138° F., and the heavy oils a specific gravity of about 0·960, and flash points varying from 118° to 178°, which meets the Admiralty specification for fuel oils for war vessels.'

" *Tar Acids.*—The tar acids, cresols, contained in the oils range from 10 to 22 per cent., and are excellent disinfectants. There is no trace either of naphthalene or anthracene.

" *Paraffin Wax.*—The oils contain from 5 to 8 per cent. of paraffin wax."

The above results were given to the author by Mr. Marshall, who stated that he had carefully prepared them for the *Iron and Coal Trades' Review*, after a number of years of experimenting and research upon the low temperature carbonisation of coal.

The results are interesting and instructive, showing that in the carbonisation of coal a few degrees of temperature either up or down materially alters the result of the process.

But in the carbonisation of coal at a low temperature it is a mistake to take it for granted that the same degree of temperature during the distillation is being exercised in the retort or apparatus at the same time, and the statement often made that such and such a distillation or carbonisation was carried out at such and such a degree Centigrade is very misleading, for no such degree can possibly obtain over the whole retort at the same time.

The illustration (fig. 48, page 132) is a section through a coke oven ; E, E are the walls of the oven heated by the gas flues, as in a horizontal by-product gas-fired oven, the heat proceeding from each side in the direction of the arrows. This illustration is designed to show the effect of the difference in intensity of heating, as will be observed at L, which represents the coke already formed by the heat proceeding from the wall of the oven, but at L′ the coke is formed to a greater depth, because the wall near L′ is more intensely heated. D represents the cold coal, and the ratio of heat progression from the two unequally heated walls is shown by the dotted lines M N and F G. The coke at L, L′ is at a red temperature, while the progress of coking is shown by the dark shaded portion representing the softening and melting portion of the coal. It will be seen, therefore, that the progression of the heat penetration is at a sharp angle, the temperature falling along the lines F G and M N ; there is no region along

these lines of the same temperature. As the temperature rises the coking proceeds in parallel lines, as from C, C and B, B, driving the gas and tar before it to the central portion at A.

Should, however, the two walls E, E and E, E be equally heated, the coking progress will proceed equally to the centre of the oven, and the line D H will then be central.

In the case of the Beehive oven, where the heat proceeds from the top downwards in one direction only, the coke is only formed on one side—that is, the upper side towards the source of heat—and the progress of carbonisation is the same, but in a vertical downward direction, differing only in respect that the gas, as already explained, is forced to find an outlet through the soft molten zone to some vertical crack in the coke or travel along the underside of this region to the oven walls, and rise against these walls.

It has been shown previously that carbonisation is a progressive operation; the substance first turns soft, then liquefies (but only momentarily), and then hardens and solidifies, unlike other substances which remain liquid under heat, and in which circulation and diffusion result, the opposite effect is produced. The heat has to penetrate already hardened coke, which is a bad conductor, and the further it has to penetrate the longer the time required, and the higher the temperature to which that portion of the charge against the walls of the retort will be submitted, and, conversely, the lower will be the temperature to which the interior mass is subjected—that is, if the heat at the source is constant and does not vary.

The process being a progressive one, a certain amount of heat is wasted in penetrating the already-coked mass before the interior is reached, so that if the gases could be taken away from the interior of a retort under a high temperature system, before they are influenced at all by heat conduction, it is probable that they would not differ very much from those produced from low temperature carbonisation (as evidence the gases and by-products from the Jameson process) for the reasons given above, that the interior mass is only heated gradually, and that between the walls of the retort, which latter may be at 900° C., and the interior may be at all temperatures ranging (according to the progress of carbonisation) down to 100° C. Therefore, low temperature carbonisation precedes high temperature carbonisation in all systems or methods of destructive coal distillation.

It is only because the gases in "high temperature" distillation are not caught soon enough, before they are exposed on their way out to a higher temperature than that at which they were made, that they are so totally different from those produced from a system of carbonisation operating below 600° C.

The fact remains that all carbonisation is carried out in its preliminary stages at a low temperature, and it may be possible in the near future to design a plant for high temperature carbonisation, producing the results of low temperature in the first instance, in the van of the heat progression, and also to obtain the results of the high temperature process later. If such a plant and process could be practicably worked, it would solve, commercially, the problem of low temperature distillation, because both processes are necessary. The high temperature process provides materials that are most essential, and so does the low temperature process, but not to the same extent, because the materials produced by the low temperature process can be obtained from other sources, and it is simply a commercial matter, as to price of production, whether the motor spirit so produced can compete with petrol or the benzol of the high temperature process.

The low temperature process is necessarily costly, both in plant and in running costs, as compared, ton for ton, with high temperature carbonisation, and, in the latter process, metallurgical coke is produced, which is an absolute necessity, and cannot be produced by the low temperature process.

The high temperature process is, therefore, bound to be carried on for the purpose of producing coke, while the low temperature process lays no claim to produce this, but a certain class of oils of the paraffin series, together with a certain quantity of motor spirit. Ultimately all processes stand or fall by their utility and their cost.

The low temperature advocates claim also to produce a residue from their distillation which contains as much as from 9 to 12 per cent. of volatile matter, free from tar, and which makes a smokeless fuel for domestic purposes, but the residue is soft and friable, and, although it ignites very easily, it burns away very rapidly, perhaps too rapidly to be economical.

It is, therefore, proposed to crush this residue and combine it with a certain small percentage of its own raw coal, and pass it through the briquetting process invented by the author, whereby a first-class fuel is made in suitably small pieces. This process is described in Chapter X. Or, on the other hand, to gasify the whole of the residue in gas producers for power and heat production. As the nitrogen obtained from the coal by submission to the low temperature process is not "fixed," it can be recovered as ammonia in the subsequent gasification process.

Mr. Marshall states on this point :—"After the liquid by-products, together with a portion of the nitrogen in the form of ammonia, have been eliminated by the low temperature carbonisation operation, there remains a solid residue of a remarkable form of coke equivalent to 70 per cent. of the original coal, which contains the bulk of the nitrogen which was present in the original coal. The coke is an ideal domestic and industrial fuel, but it is clear that if it be consumed as such then the bulk of the recoverable ammonia will be irretrievably lost. The coke can be consumed under boilers with advantage in its solid state without any further treatment, and has proved an excellent fuel, but this only goes half-way towards realising the full value of the coal. Therefore, for industrial purposes, we advance a step further and submit this low temperature coke to a secondary and well-known process of gasification, in what are termed ammonia-recovery gas producers. By this operation, not only is the nitrogen contained in the coke recovered in the form of ammonia as far as is practically possible, but on being submitted to gasification the coke produces a very large volume of producer gas.

"Each ton of coke fuel will yield from 120,000 to 140,000 cubic feet of gas, having a calorific value of 120 to 130 B.T.U. per cubic foot, which gas, in its turn, can be employed simply and economically for industrial purposes, such as boiler firing, gas engines, heating furnaces, etc.

"Let us consider for a moment what the difference is from the ammonia standpoint in consuming the coke in either a solid or gaseous form, taking 70,000,000 tons annually as a basis.

"By the preliminary low temperature carbonising process 570,000 tons of sulphate of ammonia, worth (gross) £8,550,000, are obtained, but by converting (by the secondary operation) the coke into power gas, and recovering the bulk of the nitrogen as ammonia, we should produce 2,810,000 tons of ammonium sulphate, having a gross value of £42,150,000, and, at the same time, from the 49,000,000 tons of coke (70 per cent. by weight of the original coal) we produce 120,000 to 140,000 cubic feet per ton of 'producer' gas of 120 to

130 B.T.U., which can be profitably sold at from ½d. to 1d. per 1,000 cubic feet.

"If the nitrogen contained in the low temperature coke, or for that matter, high temperature coke, is to be recovered, it is evident that it can only be effected by treating it in the gas producers. This is something for the gas companies' experts to ponder over. As a result of their operation they produce about 66 per cent. of coke from a consumption of approximately 15,000,000 tons of coal annually, which equals nearly 10,000,000 tons of coke. Part of this is used as fuel for the retort benches, part is sold to British consumers, and a considerable portion to foreigners, but whatever happens, taking previous figures as a basis, and assuming they recover ammonia equal to 25 lbs. of sulphate per ton of coal by their carbonising operations, this leaves, out of a possible 90 lbs., 65 lbs. to be accounted for. Now, 65 lbs. of sulphate of ammonia in 10,000,000 tons of coke = 430,000 tons, which at £15 per ton (gross) represents the respectable figure of loss of £6,450,000 annually."

But, in order to get this quantity of sulphate of ammonia, Mr. Marshall, as stated above, proposes to gasify all the coke made by the low temperature process, and by gas producers; he then proposes to sell this gas (low power gas) for ½d. to 1d. per 1,000 cubic feet for boiler firing and other purposes. He says:—

"The advantages would be as follows:—(1) The boiler efficiency would be increased owing to the clean condition in which the heating surface could be maintained, and the maintenance of complete combustion. (2) Constant and equal distribution of heat could be maintained, as there are no fire doors to be opened, thus avoiding the bad effects of periodically admitting cold air. (3) The cost of attendance would be greatly reduced, as one man can attend to a whole range of boilers. (4) Fire-bars and mechanical stokers, with their attendant wear and tear, would be avoided. (5) There are no ashes or clinker to remove, consequently the use of ash hoists, conveyers, and so forth, could be dispensed with. (6) There would be no costly coal elevators, cranes, and bunkers to provide. (7) If gaseous fuel can be provided at ½d. to 1d. per 1,000 cubic feet, and the boiler is slightly modified to meet the new conditions, there is no doubt that gaseous firing will eventually supersede coal-firing." He then goes on to state that this low power gas could be used to generate electricity by being "consumed direct in efficient gas engines; it is calculated that the cost of a kilowatt-hour at the switchboard would not exceed $\frac{1}{6}$ to $\frac{1}{8}$ of a penny, and the figures were given to the writer by one of the large electrical companies that 110 cubic feet of 130 B.T.U. power gas will develop in good engines one kilowatt-hour, and if used for raising steam 200 cubic feet will likewise develop one kilowatt-hour, if efficient steam turbines are employed. It will thus be seen that it would be possible to produce electric power at a cost which would compare favourably with waterfall power, and render possible in our own country the economical production of carbide of calcium, which, so far, is almost exclusively a foreign industry, and with cheap electric power many things are possible. It is clear that such a scheme as outlined must appeal vividly to electrical undertakings of magnitude in the United Kingdom."

In conclusion, Mr. Marshall sums up in the following words, "It is necessary to distinguish such a process as described from the ordinary gasworks operations, which operations have in view, first and foremost, the production of a maximum yield of gas, that being the primary object, the tars and ammonia being of secondary consideration. On the other hand, the low temperature process may have for its primary objects the recovery of tar oils, or manufacture of a

domestic fuel, or power gas and ammonia, the relative importance of one to the other being determined by final production. This is the fundamental distinction between the two systems.

"Beyond, perhaps, the sale of coke for domestic purposes, there is no question of competition. Each process has its distinct sphere of operation and usefulness; anyway, high temperature carbonisation is necessary for benzene production, as without this commodity the British dye industry could not exist.

"It must be admitted, however, that a plentiful supply of motor spirit, fuel oils, etc., besides a free-burning, smokeless fuel, are likewise urgent necessities, and it is in this direction that low temperature carbonisation is working.

"With practically everything in the melting pot, industrially speaking, especially as regards the price of coal, wages, material, etc., the costing of a balance sheet at the present moment showing the net profit to be derived from the conversion of the coal would be an extremely hazardous proceeding, but from the past six years' experience of the working costs of carbonisation, fractionation of the oils, etc., the writer is convinced that, with any conditions approaching the normal, low temperature carbonisation would return a high yield on the capital invested."

It is a pity Mr. Marshall did not give any figures with reference to this most important question regarding the carbonisation of coal at a low temperature, because, whatever scientific or other merits such a process may possess, unless it will pay to carry out commercially, it is worthless.

He admits that the most that can be expected from it is a certain quantity of motor spirit, tar, and soft coke residue for domestic fuel. The gas that is produced by the process is for the most part absorbed in the heating of the retorts, and, as will be gathered from his description, the proposal is either to have practically no gas for sale with the domestic fuel, or to gasify this fuel in gas producers for the purpose of gaining the ammonia, and the manufacture of a very poor gas unsuitable for the appliances now installed for domestic and manufacturing purposes, or even for equivalent burning under steam boilers, without expensive additions and alterations.

Processes for obtaining the remnants of ammonia, 75 per cent. of the nitrogen content of the coal, were first patented by Messrs. Young & Beilby (British Patent No. 5,084, in the year 1882), and several subsequent patents were taken out by Mond (British Patents Nos. 3,923 and 3,821, of 1883, and 8,973, of 1885), and a comparative statement of the gases produced by Messrs. Young & Beilby with that made by the Wilson producer is as follows :— *

	Wilson Producer Gas.	Young & Beilby Gas.
Carbon dioxide,	7·14	15·40
Hydrogen,	12·15	34·53
Carbon monoxide,	19·83	10·72
Methane,	3·91	4·02
Nitrogen,	57·24	35·33
	100·27	100·00

* G. Lunge, "Coal, Tar, and Ammonia," p. 718.

A statement of the cost of producing gas and ammonia by the Mond process, by Emil S. Mond, managing director of The Power Gas Corporation, Ltd., is as follows :— *

STATEMENT OF ANNUAL WORKING COST OF 20,000 HORSE-POWER PLANT WITH AMMONIA RECOVERY WORKING CONTINUOUSLY AT FULL LOAD FOR 365 DAYS OF 24 HOURS.

Total full (91·250 tons), including that required to raise necessary steam, at 6s. per ton,	£27,375
Wages at producers, boilers, sulphate recovery and evaporating plants, including handling of coal and ashes, shipping of sulphate,	4,859
Sulphuric acid (at 30s. per ton). Also lubricants, lighting, stores, repairs (including wages and utensils for same),	6,456
	£38,690
Less 2,920 tons sulphate at £10 per ton,	29,200
Net cost per annum,	£9,490

Cost of available gas per 1,000 cubic feet 0·2213d.

It will be observed that these costs are based upon coal at 6s. per ton, and wages normal for labour costs ; 30s. per ton for sulphuric acid, etc. These were pre-war costs. How would such a process be able to survive at the present inflated costs ?

Mond gas has an average composition as follows :—

Carbon dioxide,	17·1
Carbon monoxide,	11·0
Olefines,	0·4
Marsh gas,	1·8
Hydrogen,	27·2
Nitrogen,	42·5
	100·0

One ton of coal produces about 160,000 cubic feet of gas, for which about $2\frac{1}{2}$ tons of steam is used, for the purpose of collecting the ammonia ; but, as the carbon present in the producer will only convert about 1 ton of steam, the balance of $1\frac{1}{2}$ tons passes through undecomposed as water vapour, and has to be condensed. Mond, to a greater extent, recovers the initial heat of the steam in his process, but the gas is very poor, the plant is exceedingly cumbersome and expensive, and the gas cannot be used in most industries without scrapping existing plant, using at present good coal, or rich gas. It is a serious mistake to think that a change-over from coal-firing or rich gas-firing to a poor gas, such as produced in the Mond process, is practicable without a new plant constructed to deal with the power gas. The question comes now to the point—that is, the utilisation of low temperature carbonisation under existing circumstances of high costs of labour and materials. It may be that the first cost of a plant for making Mond gas, and recovery of ammonia, together with the working costs, will prove prohibitive. There is still the author's alternative scheme to convert the low temperature coke into high temperature hard metallurgical coke, securing at the same time a fair proportion of the ammonia. The high temperature coke always finds a ready market, and it would not

* *Journal Society of Arts*, April, 1906.

require any further plant to produce it, if any of the numerous by-product plants were brought into use for this purpose.

The proposals of the author are as follows :—Carbonise the coal at a low temperature to obtain the products that are indispensable —*e.g.*, motor spirit and the paraffin series of oils ; then mix the residue with a certain percentage of its own raw coal and carbonise it at a high temperature, to make first-quality foundry coke, in any oven capable of doing so ; *or*, in a horizontal oven, to make furnace coke ; *or* make the residue with about 20 per cent. of its own coal into briquettes, by the process described by the author in Chapter X., whereby a first-class domestic fuel is made in suitable small blocks, which are hard enough to stand a good deal of handling and carriage, are easily lighted, burn well in any fire or grate, without or with forced draught, do not disintegrate, and are absolutely smokeless. Such briquettes are unlike any hitherto produced, since they are made without external pressure, and by a partial carbonising or coking process, which renders them very spongy and light.

The great fault with all briquettes on the market, made with a binder such as are anthracite briquettes, is that they are too solid, owing to the pressure employed to harden, stiffen, and shape them. When anthracite duff is thus treated, the briquettes cannot be burned without a blast or good chimney draught, since the hard crust cannot be penetrated by the oxygen of the atmosphere at ordinary pressure. Briquettes made of good coal with pitch as a binder offer the same disability, and devices are not uncommon in which holes or perforations right through the briquette have been made, for the purpose of allowing the air to penetrate the briquette, in order to make it burn under normal conditions.

The new briquette, being spongy, like a piece of soft coke (but only caked, and not coked to the extent of making the coke cells hard), is thus easily penetrated by the atmosphere, and burned. The manufacture of these briquettes is extremely simple. Anthracite or coke duff is mixed or ground with about 20 per cent. of bituminous coking coal, damped to prevent dusting, and then filled into moulds automatically fastened and air-tight. The moulds are then passed continuously through a heated flue, so that each briquette is subjected to a temperature under 750° C.—usually about 600° C.—for about 10 to 15 minutes, when the coking coal agglomerates and binds together in a spongy mass the anthracite or coke duff, thus forming briquettes which fall out of the moulds as they are automatically opened (see Chapter X.).

Since the low temperature process provides this residue, the above seems to be the most practical solution in dealing with it, securing the low temperature products, and at the same time making high temperature coke, and high temperature by-products or domestic fuel.

The coke made by this process is extremely dense and hard, and fulfils all the requirements of foundry coke.

Theoretically, metallurgical coke should be as hard and dense as it can possibly be made, for the reasons already given, while, on the other hand, any fuel produced from coal, for use in a domestic or other grate, where the chimney draught is normal and very slight, should be porous and light, so that it is easily oxidised or burned, whereby a bright fire is produced, requiring little or no attention, and where the heat units are given out for heating purposes, and not otherwise wasted.

The waste of fuel on any fire or furnace is made apparent by the issue of smoke, which means that the hydrocarbons distilled from the coal at a low temperature are not being consumed, and this arises from several causes—

lowness of temperature in the furnace or grate; absence of high temperature media through which the smoke may pass, or the placing of thick layers of raw coal on the surface of a fire, for, when this is done, the coal immediately resting on the hot fire below is just beginning to get warm, and as the temperature rises to about 400° C. copious discharges of gases ensue, which rising through the cold coal are not ignited, but pass up the chimney, and are lost in the form of smoke. The problem of this enormous waste of fuel, and the consequent pollution of the atmosphere, is taxing the best brains in the country. The rational way would be to carbonise all coal at the pit mouth, leaving what is required for special purposes only, such as for gasworks for the supply of towns, to be transported. But even this could be avoided, now that candle power in gas lighting is no longer required, but heating units, and this kind of gas can be made from coke with a small admixture of coal. It is, however, quite evident that in the near future something will have to be done to prevent the great waste, both in the domestic grate and the furnace of the factory; and it is not only a sanitary proposition, but one of practical economy, demanding the serious consideration of all concerned in the mining and using of coal, and in its carbonisation.

CHAPTER V.

CHARCOAL.

From the earliest times of which we have any record we find mention of the manufacture of charcoal by exposing wood to heat, in order to drive off the gaseous elements and to obtain the solid carbon.

The process was no doubt introduced for the purpose of obtaining fuel that was smokeless, and did not flame, for use in metallurgy and other purposes. It is quite obvious that wood is objectionable as a fuel, for many purposes, on account of its flaming, its bulk, and smoke production, and the method of rendering it more serviceable as charcoal was thus recognised very early.

Charcoal is very porous, black in colour, and is easily reduced to a fine powder. When made at a high temperature it has a metallic ring when struck; it is lighter than water, and, therefore, floats on its surface for a time; it does not conduct electricity, or heat, to any extent, and does not burn with flame—that is, flame produced by hydrocarbons—but will burn with flame in a grate where it is in pieces and of a certain depth and incandescence. In this case, the flame is produced by the reaction of the combustion of the charcoal in the lower portion of the grate, producing carbonic acid gas, CO_2; as this gas passes upward through the incandescent charcoal, the oxygen of the CO_2 is partly absorbed, producing another gas, CO. This latter gas is combustible, and on reaching the surface of the incandescent charcoal it takes fire, and burns with its characteristic blue flame.

Composition of Charcoal made from Wood.—The following tables, taken from Wagner's *Jaresbericht*, 1855, by Dr. Percy, shows the composition of wood charcoal prepared at three different places :—*

I. Beechwood Charcoal in Piles or Heaps. II. Hard Charcoal from Wood Vinegar Works. III. Light Charcoal from Wood Gasworks.

	I.	II.	III.
Carbon, . . .	85·89	85·18	87·43
Hydrogen, . . .	2·41	2·88	2·26
Oxygen and nitrogen, .	1·45	3·44	0·54
Ash, ...	3·02	2·46	1·56
Water, . . .	7·23	6·04	8·21
	100·00	100·00	100·00

He also quotes from Violette, in the *Ann. de Chim. et de Phys.*, s. 3, 1851, vol. xxxii., p. 322, with regard to the composition of charcoal prepared from the same wood, but at gradually increasing temperatures, which are shown in the following table :— *

* Percy's "Metallurgy," p. 354 (Fuel, etc.)

TABLE SHOWING THE PERCENTAGE COMPOSITION OF CHARCOAL PREPARED AT DIFFERENT TEMPERATURES FROM WOOD PREVIOUSLY DRIED AT 150° C.

No.	Temperature in Centigrade Degrees at which Carbonisation was effected.	Composition of Charcoal Produced.				Observations.
		Carbon.	Hydrogen.	Oxygen, Nitrogen, and Loss.	Ash.	
I.	150°	47·51	6·12	46·29	0·08	The products obtained at these temperatures cannot properly be termed charcoal.
II.	200°	51·82	3·99	43·97	0·22	
III.	270°	70·45	4·64	24·06	0·85	
IV.	350°	76·64	4·14	18·61	0·61	
V.	432°	81·64	1·96	15·24	1·16	
VI.	1,023°	81·97	2·30	14·13	1·60	
VII.	1,100°	83·29	1·70	13·79	1·22	
VIII.	1,250°	88·14	1·41	9·25	1·20	
IX.	1,300°	90·81	1·58	6·46	1·15	
X.	1,500°	94·57	0·74	4·03	0·66	
XI.	Beyond 1,500°	96·51	0·62	0·93	1·94	

"The wood operated on was that of black alder or alder buckthorn (*Rhamnus Frangula, L.*), which furnishes a charcoal suitable for gunpowder."

I. and II. were not considered proper charcoal.

III. was what the French term *tres-roux*, from its red colour, and at the temperature was commencing to be fit for pulverising, but was brown in colour.

IV. was black charcoal like that of the succeeding numbers.

The following table, taken in conjunction with the last one, is interesting, as showing the proportions of the elements extracted at the temperature ranging from 150° upwards :— *

TABLE SHOWING THE NATURE AND PROPORTIONS OF THE FIXED AND VOLATILE MATTER PRODUCED BY THE CARBONISATION OF WOOD (PREVIOUSLY DRIED AT 150° C.) AT DIFFERENT TEMPERATURES.

No.	Temperature in Centigrade Degrees at which Carbonisation was effected.	Products of the Decomposition of 100 Parts by Weight of Wood by Carbonisation at different Temperatures.					Sum of the Numbers in each Horizontal Line.
		Composition of the Solid Matter in Charcoal.			Composition of the Matter Volatilised.		
		Carbon.	Gaseous Elements (H_2, O., N_2.)	Ash.	Carbon.	Gaseous Elements (H_2, O_2, N..)	
I.	150°	47·51	52·41	0·08	. . .	. . .	100·00
II.	200°	39·95	36·97	0·18	7·56	15·34	100·00
III.	270°	26·17	10·65	0·32	21·34	41·52	100·00
IV.	350°	22·73	6·75	0·18	24·78	45·56	100·00
V.	432°	15·40	3·25	0·22	32·11	49·02	100·00
VI.	1,023°	15·37	3·12	0·30	32·14	49·11	100·04
VII.	1,100°	15·32	2·86	0·22	32·19	49·41	100·00
VIII.	1,250°	15·81	1·91	0·22	31·70	50·36	100·00
IX.	1,300°	15·86	1·40	0·20	31·65	50·89	100·00
X.	1,500°	16·37	0·83	0·11	31·14	51·55	100·00
XI.	Beyond 1,500°	14·48	0·23	0·29	33·03	51·97	100·00

* Percy's "Metallurgy," p. 355 (Fuel, etc.)

Dr. Percy, in commenting upon these experiments of Violette, remarks :— "That, in order to show the use of this table, suppose, for the sake of example, that a question should be asked concerning the effect of carbonising wood at 432° C. The answer will be found in the horizontal line V., and is as follows :— The weight of the charcoal is 15·40 + 3·25 + 0·22 = 18·87 per cent. of the dry wood, and the charcoal consists of 15·40 per cent. carbon, 3·25 per cent. of oxygen, hydrogen, and nitrogen, and 0·22 per cent. ash. In producing that weight of charcoal from 100 parts by weight of dry wood, the matter volatilised is 32·11 + 49·02 = 81·13 per cent., and consists of 32·11 per cent. of carbon, and 49·02 per cent. of the gaseous elements, hydrogen, oxygen, and nitrogen."

The experiments of Violette were conducted in glass tubes, in the laboratory, and out of contact with the atmosphere, and it is stated that he operated upon a small quantity of dried wood equal to 1 gram; this he introduced into a thick piece of glass tube, which must have been sufficiently spacious inside to withstand the expansion of the gases, as it is also stated that he heated the ends of the tubes, after inserting the wood, drew them out, and sealed them; he then exposed these tubes to temperatures of 160° C. to 340° C.

It is obvious when conducting these experiments in small tubes, and exposing them to a higher temperature, that the tubes would burst by the expansion of the liberated gases, and this did frequently occur, but he overcame it by heating the tube at the end to softness, so that the expanding gas gradually swelled out of the glass, and then, forcing its way through a fine hole, escaped. Making charcoal under pressure by this means made a difference in the results obtained from those where the pressure was relieved by the free escape of the gases, as will be seen by the following tables :—

TABLE SHOWING THE YIELD OF WOOD CHARCOAL BY CARBONISATION WHEN THE VOLATILE PRODUCTS ARE NOT ALLOWED TO ESCAPE, BUT ARE RETAINED UNDER PRESSURE.

No.	Temperature of Carbonisation in Centigrade Degrees.	Yield of Charcoal per Cent. of the Dry Wood.	
		By Carbonisation not under Pressure.	By Carbonisation under Pressure in Hermetically-sealed Vessels.
I.	160°	98·00	97·4
II.	180°	88·59	93·0
III.	200°	77·10	87·7
IV.	220°	67·50	86·4
V.	240°	50·79	83·0
VI.	260°	40·23	82·5
VII.	280°	36·16	83·8
VIII.	320°	31·77	78·7
IX.	340°	29·66	79·1

TABLE SHOWING THE COMPOSITION OF WOOD CHARCOAL MADE AT DIFFERENT TEMPERATURES UNDER PRESSURE.

No.	Temperature of Carbonisation in Degrees Centigrade.	Composition per Cent.			
		Carbon.	Hydrogen.	Oxygen, Nitrogen, and Loss.	Ash.
I.	160°	49·02	5·30	45·53	0·15
II.	180°	56·52	6·19	37·09	0·20
III.	200°	61·04	5·25	33·42	0·29
IV.	220°	66·42	4·98	28·01	0·59
V.	240°	67·13	5·17	25·93	1·77
VI.	260°	67·62	5·10	25·20	2·03
VII.	280°	64·60	5·42	26·78	3·20
VIII.	320°	65·62	4·76	25·55	4·07
IX.	340°	77·07	4·71	14·38	3·84

The product of two first trials up to a temperature of 180° C., produced under pressure, was not very different in appearance from that produced without pressure at a temperature of 280° C.; it was of a light brown colour, but in chemical composition was entirely different from the latter, of which the percentage composition was—carbon 72·64, hydrogen 4·71, oxygen, nitrogen, and loss 22·08, ash 0·57.

Violette also makes the extraordinary statement that when wood is exposed under pressure to 300° C. and upwards it fuses, adheres to the experimental tube in which it is heated, loses all traces of its organic structure, is hard, brittle, and hollow, and resembles coke made from caking coal (*houille grasse*). He also states that from his experiments he is of opinion that a certain proportion of the ash contained in wood is volatilised when the carbonisation is carried on without pressure—that is, when the gaseous products are allowed freedom of escape. Dr. Percy thinks this is questionable, but it may be so if the operation is carried out at a high temperature rapidly. The heavy hydrocarbons may carry away with them certain amounts of ash, in very fine division, mechanically, whereas under pressure this would not be possible, since the gaseous elements would have to make their escape through a comparatively small aperture, and the tendency, therefore, for conveyance would be reduced, as compared with vapours rising freely, rapidly, and unimpeded.

The large proportion of ash recorded in the last table is remarkable when compared with the first table, where the carbonisation was carried on without pressure.

Violette also states that when charcoal is manufactured at a low temperature it is soft and burns very easily, but when produced at a very high temperature it is hard, and is only ignited with difficulty; in this it resembles coal. When coking coal is submitted to carbonisation, at a low temperature, the coke produced is very soft, friable, and very easily lighted, because of the retention of a large proportion of hydrocarbons; when it is produced at a high temperature these hydrocarbons are entirely volatilised, the exposure to the high temperature consolidates and hardens the carbon residue, so that, as with coal, similar results may be obtained from wood, treated under the same conditions.

Wood charcoal, and also charcoal produced from the carbonisation of bones, or horn, and called animal charcoal, possess the power of absorbing gases to

a very large extent, according to De Saussure, who made a considerable number of experiments on the absorption of gases by charcoal made from boxwood, as shown by the following table :—

TABLE SHOWING THE NUMBER OF VOLUMES OF VARIOUS GASES ABSORBED BY ONE VOLUME OF BOXWOOD CHARCOAL.

Ammonia,	90	Carbonic acid gas,	35
Hydrochloric acid gas,	85	Carbonic oxide,	9·42
Sulphur dioxide,	65	Oxygen,	9·25
Sulphuretted hydrogen,	55	Nitrogen,	7·5
Olefiant gas,	35	Hydrogen,	1·75

The extremely porous nature of charcoal offers an enormous surface exposed to the contact of the gas, and this is strikingly exemplified by the following experiment :—Take a glass tube, closed at one end, and fill it with ammonia gas, then invert it over a cup of mercury into which a piece of freshly burned charcoal has been inserted, as shown in fig. 50. The charcoal will rapidly

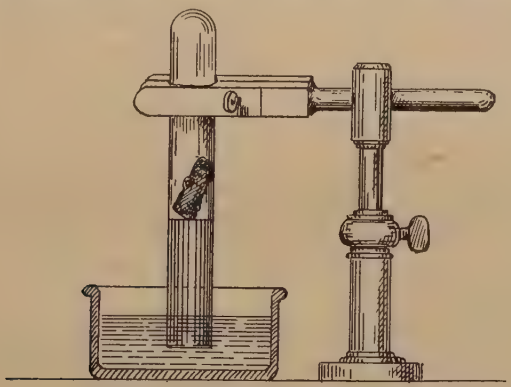


Fig. 50.—Charcoal in Mercury.

absorb the ammonia gas, so that a partial vacuum is formed in the tube, and the mercury will rise up the tube, carrying the charcoal floating on the top of it ; if the charcoal be quickly removed and placed on the hand, the ammonia will volatilise rapidly, producing a sensation of cold. Charcoal made from close-grained, hard wood absorbs the largest amount of gas ; logwood charcoal is stated to absorb about 111 times its volume of ammoniacal gas.

Noxious gases, proceeding from decaying matter, are readily absorbed by wood charcoal, and by this means vitiated air has been rapidly sweetened.

Charcoal is used in many instances to absorb liquid and solids as well as gases, and is used to great advantage as a decoloriser ; if some logwood dye infusion be shaken up with some powdered charcoal, the filtered liquid will be quite colourless, the colour having been mechanically extracted from the water, as the charcoal can be made to yield up the colour by treating it with an alkaline solution.

The decolorising power of animal charcoal, however, supersedes that of wood charcoal, and in this respect the former is generally used for the purpose, as in the case of sugar refining and decolorisation.

Charcoal is a very permanent form of carbon, and is with difficulty altered, except at high temperatures, or by combination with other elements, so that when wood is turned into charcoal it ceases to decay, air and moisture having no effect upon it at ordinary temperatures. This fact is taken advantage of when stakes of wood have to be driven into damp earth; the portion underground is protected by charring on the surface, which then resists the action of the atmosphere, under the conditions of moisture, and probably also the chemical action of the soil.

Charcoal as fuel will produce twice the amount of heat that an equal weight of wood will give, since the carbon in the former is concentrated, while in the latter a great part of the heat developed by the combustion is absorbed in evaporating the moisture it contains.

Charcoal is an ideal form of carbon for metallurgical purposes; it is smokeless, easily lighted, burns completely without caking, contains very little ash, and none of the objectionable elements that are found in coal, such as sulphur and phosphorus. It is readily oxidisible, and is, therefore, well fitted as a reducing agent in absorbing the oxygen from oxidised ores, and it is largely used in producing the highest quality of iron and steel.

All wood will not make the same quality of charcoal; that made from hard wood is the best, and in the ordinary method of manufacture the charcoal retains its original shape and form, and is thus quite distinct from coal, although both be submitted to the same process, and in the same apparatus; take, for example, the manufacture of charcoal in a retort; the charcoal after carbonisation will be found to have the same form, but be changed in character. It will be black in colour, brittle, and break with a conchoidal fracture: the fibre has thus been destroyed without loss of shape or semblance; in the case of coking coal submitted to the same treatment, in the same retort and at the same temperature, the coal not only loses its physical appearance, but undergoes a complete physical change, passing from the hard, dense, rock-like mass, becoming completely fused, and during the carbonisation forming an amorphous, pasty, spongy mass, which, under the action of the escaping gases, is rendered extremely porous, and by the continued high temperature of carbonisation is hardened and coked.

It will be observed that in the case of coal the porosity is caused by the swelling of the pasty mass by the gas development within it, whereas in the case of charcoal the porosity is caused by the evacuation of the gas passing out of the natural pores of the wood; the wood does not, as with coking coal, thus fuse and swell up in parting with its gaseous contents, but remains in its original form until the gaseous elements have passed off. A complete skeleton of carbon is left, termed charcoal.

Dry, non-coking coal will assume this same character under similar treatment—that is, it does not fuse—and the gaseous constituents are liberated, as in the case of wood, above described, leaving the block of coal practically the same in shape as before treatment, but very tender and friable, having no coherence.

Thus, it will be inferred that charcoal, to a certain extent, resembles coke in being hard, sonorous, and porous, but without having been fused in the sense that coke is fused during its production: but, on the other hand, it must be admitted that a kind of partial fusion takes place in the pores of the charcoal during carbonisation, from the fact that it assumes all the characteristics of coke in the matter of hardness, brittleness, and its metallic sound when struck.

It is possible that when wood is submitted to destructive distillation, and

gas is evolved containing heavy, tarry hydrocarbons, that these in making their escape are, after their formation, deposited on the cell structure of the wood, and the skeleton of carbon contained in the wood, in passing from its liquid state to that of charcoal under the influence of heat, is converted into solid carbon by a process analogous to that which takes place in the coking of coal, apart from the swelling up or amorphous process of the latter.

In the case of the carbonisation of coal the exit of the gaseous elements is accompanied, as already pointed out, by a swelling up in coal of high coking quality, where the fusion is accompanied with a stiff doughy mass; but in the carbonisation of other quality coal where the fusion is complete, the swelling up does not take place, but a very liquid, amorphous mass results, with very fine pores, the gases escaping with facility, and rapidly; something of the same kind may occur in the coking or charring of charcoal, but microscopically, and confined to the pores of the wood only, where exceedingly minute bubbles of gas may exude, formed of the tarry bodies which under the high temperature are coked, and thus stiffen and harden the cells of the charcoal.

This theory is advanced here by reason of the fact that the higher the temperature at which charcoal is made the greater the amount of carbon it contains, so that it is inferred that the heavy hydrocarbons are deposited, coked, and retained in the pores of the charcoal, and, further, charcoal, when exposed to high temperature, becomes harder, as is the case with coke made from coal, showing that the coking process, or the final hardening of both charcoal and coke, are analogous.

The proof of this theory is shown by the table on p. 149 dealing with Violette's experiments in making charcoal with and without pressure, a most remarkable rise in the amount of carbon retained being obtained by raising the temperature under pressure, as compared with the same treatment without pressure. This bears out the assumption that hydrocarbons are deposited, and become charcoal, during the carbonisation of wood, when they are not permitted freedom of escape.

This theory was applied, practically, by the author in designing a vertical coke oven for the treatment of Lanarkshire coal, which is fully described in Chapter IX., where high temperature combined with pressure was completely successful in making dense, hard coke from coal that could not be coked in the ordinary horizontal by-product oven; not only was the coking process successful, but the yield of coke in this oven, from ordinary coking coal, was 5 per cent. more than was possible in the horizontal oven, and over 15 per cent. more than in the Beehive oven, from the same coals. No heavy, thick tar was made, from which fact it is obvious that the heavy, tarry matters were retained in the coal mechanically, and thus increased the yield of coke.

Although it has been recorded by Violette that he fused the wood in making charcoal, and thus made coke from wood, it must not be taken for granted that the two forms of carbon—coal and wood—are identical, as it is extremely doubtful, if not impossible, that charcoal of the same physical qualities and appearance made from wood can be made from coal.

It is generally admitted that coal has had a ligneous origin, but perhaps it would be going too far in this direction in making this universally applicable to all coal. The finding of wood spores and the petrified forms of leaves in coal, and branches and trunks of trees in the coal measures, does not actually carry the theory further than that the coal was formed contiguous to these petrified forms found in it, and was actually deposited around them.

In all theoretical considerations with regard to the transformation of wood into coal, it must be borne in mind that conclusive evidence is lacking. Carbonisation at a very low temperature, under pressure, and under atmospheric conditions which at that period of the earth's existence must have been extraordinary, and probably altogether different in chemical constituents from the present, may have taken place; large deposits of carbon or hydrocarbons, from the atmosphere, under conditions which have now completely changed, may have formed the coal in some instances, or consolidated in others the growing masses of vegetation at that period.

It is not very clear, as some have suggested, that the vegetable matter underwent decomposition in transformation into coal, as it is well known that decomposed vegetable matter forms humus, the chief constituent in its transformation to vegetable soil. It is also very questionable whether any vegetable matter, including wood after decomposition, will form charcoal, so that if the theory of carbonisation of vegetable matter in the formation of coal by passing through a process of low temperature charcoal be maintained, it is obvious that it was from undecomposed material.

Suppose, for instance, that charcoal of a *trés-roux* nature was formed by the heat of the earth, by some sudden deposit of several hundred feet of material upon the growing vegetation, by the arresting of the heat radiation from the surface, by such a heaping up of material such as forms the geological layers between the seams of coal, then the temperature, by reason of the pressure, would rise, apart from the accumulation of temperature due to non-radiation, and by this means a temperature may have been reached at which the vegetable matter so buried would pass through a process of fermentation and slow carbonisation into a low temperature charcoal; but as the tarry bodies in the wood are retained in low temperature carbonisation, these form the kind of charcoal produced by Violette, and ultimately form coal.

The term carbonisation is used here for want of a better one to express the process, but it is not carbonisation in the real sense that is meant, because the process may have extended into years and perhaps ages, and would be applicable to that class of coal in particular known as non-coking coal, and low in volatile hydrocarbons, such as dry steam coal and anthracite.

It is supposed by some writers that anthracite has been formed by heat from volcanic action, after the coal had been formed, causing the volatile hydrocarbons to be expelled, but such a theory is doubtful, owing to the facts revealed in the coal deposit, as being practically the same in bulk, whereas if heat—that is, volcanic heat—had been applied to the coal after formation, in the thicker seams, it would have overheated that portion nearest, and turned it into coke; but this is only observed in rare instances where the volcanic intrusion crosses the coal seam, but in the case of a lower temperature than could be applied by volcanic action by the sudden deposit of great thickness of matter, over the live vegetable matter, there is the possibility of a gradual process of change, by rise of temperature, that would produce a sort of wood charcoal of a light red colour to commence with, if the temperature was not high; this would probably be after a period of fermentation had passed, by which the ligneous nature of the vegetable matter would be changed, and give rise to the new physical character of true coal.

It is evident that some process of the kind has operated upon this class of coal in its formation, if the theory is held that the coal has been derived from vegetable matter, and from the large deposits of oil shale that quite possibly form the condensate of the volatile hydrocarbons, which were slowly expelled

from the coal in process of formation. Such deposits of shale and oil may be near, or far, from their source of origin, because the gaseous form of the oil would be capable of travelling great distances underground, and the deposit, by aid of water at subsequent periods of time, would be transported until a position where it became fixed, was reached often at great depth.

In such a process of formation of coal, the fermentation under pressure and time would ultimately destroy the ligneous nature of vegetable matter, except the resinous part, and this is what is usually found in coal when it is subjected to a microscopical investigation, while the long continuation of the process changes the colour to black.

In the class of coal termed cannel coal, this appears to have passed through a semi-liquid state before it became solid, and may have been the heavy pitchy distillate of this process, as it is quite different from ordinary coal, having a conchoidal fracture, being absolutely amorphous, without lamination, and capable of taking a high polish. Jet is a very hard kind of cannel coal, and probably formed under very great pressure, whereby the high percentage of its hydrocarbons has been concentrated; this class of coal cannot have been formed by, or under, the same conditions as ordinary coal, and has certainly not passed through the state of low temperature charcoal.

Charcoal Manufacture.—The process of converting or carbonising wood into charcoal is extremely simple and of great antiquity, as we learn from history that the ancients soon appreciated the value of the concentrated carbon in charcoal for their various purposes of metallurgy and the industrial arts, where wood, owing to the smoke it emits, and its other disadvantages as a fuel, could not be used.

No doubt the first fire of any considerable size kindled with wood, after the smoke and flame had passed away and the embers of charcoal were glowing under the influence of the breeze, have suggested the manufacture of charcoal, and perhaps the unconsumed embers of these first primitive fires constituted the first specimens of charcoal to be used.

It would be obvious to this primitive age, observing that when wood is put on a fire it occupies a large space, produces smoke and flame, and is very difficult to control, and it is difficult to make use of the heat of combustion to any extent, that when the flame had ceased, and charcoal remains were discovered to be capable of concentration and by the application of air to develop a high, local, clean heat, the manufacture of charcoal would probably have been determined upon.

Probably the first charcoal ever made expressly for the purpose was made in an open heap with access of air all round, forming a great pile or bonfire; perhaps when it had sufficiently burned it was drenched with water or sand, and the charcoal thus secured, resulting in a mixture of charcoal, ash, and partly carbonised wood. But in those early days, such charcoal would answer the purpose of their primitive needs.

As the world progressed a demand soon arose for properly formed charcoal —that is, charcoal made without the admission of air—and probably the first made upon this principle was made in heaps, covered up with mud, sand, or turf, a process that still exists, and when properly carried out gives tolerably good charcoal.

Charcoal Manufacture in Circular Piles.—For the purpose of making charcoal certain kinds of wood have to be selected; hard woods make the best kinds.

It is usual to select a spot in a wood which has been cleared, and to form a circular pile of the wood cut into suitable lengths; the wood in the early days

may have been simply thrown together in a heap and covered up with turf or clay or mud.

Modern charcoal burning heaps are made on a regular system, as shown in fig. 51. The commencement is made by driving some stakes into the ground, forming the centre of the pile, as at *a*. The wood cut to suitable lengths is now piled on end round this central fixture, which acts as a chimney in the initial stage of carbonisation.

The wood is piled up as shown in the illustration, and at the top the smaller branches are placed; the pile of wood is now covered up with a layer of turf or clay or mud, as shown at *e*, *e*.

The logs or pieces of wood nearest the centre are piled up perpendicularly, while those receding towards the circumference are given an angular inclination, as shown in the illustration.

Beneath the outside covering of turf (if turf is used, it is generally placed with the grass side inwards) the smallest branches, twigs, and broken small pieces of wood are heaped up several inches thick, all over the piled wood, and, in order to secure the heap so that it may not be disturbed by the weather or by the charring process, it is often pegged down on the circumference with small stakes driven into the ground; into these small stakes the small branches

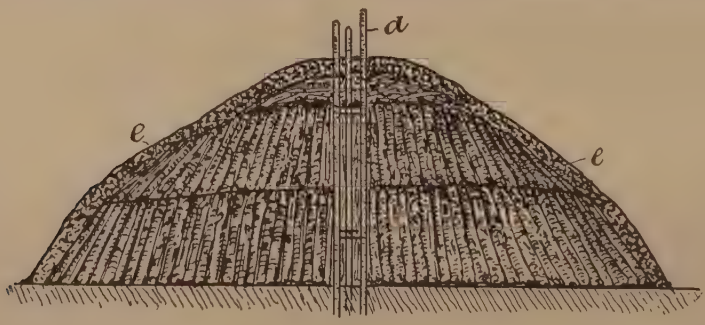


Fig. 51.—Section of Charcoal Heap showing Method of Piling the Wood.

of the wood are twined, so as to make a kind of network around the base of the pile, which supports and keeps in place the outer covering of turf or clay, soil or mud, which is next applied and is carefully solidified, all cracks or crevices being plastered up and made as air-tight as possible, the covering being made thickest and heaviest at the top, where it will be exposed near the chimney to the greatest heat.

The pile is now fired, and the commencement is usually made very early in the day, on account of the constant attention required during the initial stage of carbonisation.

The state of the weather is another factor that requires due consideration in the firing of a pile, because bad weather may destroy completely proper ignition of the pile, and produce over-burning in one part and under-burning in another; it is, therefore, absolutely necessary that the pile should have all conditions, including the weather, favourable for a regular kindling of the wood. This is commenced in the centre of the stakes, *a*, which is generally filled with selected pieces of dried wood which may be easily kindled, and when these have been well burned more wood or charcoal is filled into this central space through the top, to keep the central fire burning until the piled wood

surrounding the chimney has developed a certain amount of incandescence. The top is then closed with some turf pressed well down into the chimney.

Hitherto, during this stage of the lighting-up of the pile, the air for combustion of the central stack of wood in the chimney has been drawn in through the brushwood surrounding the circumference of the pile, but now that the chimney has been closed, the draught has been stopped, and combustion arrested. A period of sweating now commences, by reason of the heat in the interior of the pile; the wood is gradually desiccated, and a quantity of steam is evolved through the covering of the pile.

As the interior mass of the wood nearest the chimney becomes desiccated and commences to carbonise, the heat in this part develops to the surface, and by drying the turf and outer covering the latter begins to shrink and crack, affording the draught a chance to operate once more. The space round the base is now closed with turf, to check the draught, but this is not done until the sweating stage has completely ceased and the interior is desiccated.

The whole covering is now inspected and plastered up, all cracks stopped, and the whole made quite air-tight, and left for a few days, generally three or four. Combustion has now ceased practically, the internal heat acting now simply as a carboniser, but the pile must now have the attention of the charcoal burner, otherwise, closed as it is, the process would cease, since the reaction is not exothermic, and requires heat to be kept up, and this must be done at the expense of the combustion of a further amount of the wood in the pile, by the inlet of a fresh supply of air. This is accomplished by poking holes or vents through the outside covering about the centre between the base and the top of the pile, or about the position shown in fig. 51, at the top of the first pile of wood. A large quantity of dense smoke now escapes from these vents, the product of the combustion, or rather the partial combustion of the tarry matter of the gases that are now commencing to be distilled from the wood. Atmospheric air being insufficient in quantity to burn the gases completely, and as they are mixed with a certain quantity of water vapour they are expelled in the form of dense smoke, which gradually clears away, the gases ultimately becoming transparent and of a bluish colour.

These holes or vents are then closed, and another set are made lower down in the pile, from which escape dense fumes or smoke, showing how the process of the carbonisation of the pile is progressing. These vents, after the character of the smoke has changed, may also be closed and others opened lower down, and so on until no dense, coloured smoke is emitted; this shows that the carbonisation, as far as can be procured by means of the heat of combustion with atmospheric air admittance is concerned, is quite complete. The pile is now closed completely, and all air vents and smoke vents stopped up, and the products of the distillation of the hydrocarbons of the wood during this last stage of carbonisation are either condensed in the outer covering or make their escape through it.

The pile is now left for a few days, so that the carbonisation may be completed—that is, the penetration of the necessary heat to the interior of each piece of wood so that the whole may be charred to the centre.

When the carbonisation has thus proceeded in this manner satisfactorily, the pile is opened at the side, near the bottom and the charcoal is withdrawn, this operation proceeding round the pile at intervals, care being taken at each interval to cover up the breach to exclude the air, while the charcoal already recovered is immediately quenched with water.

In carbonising wood in this manner, the object is to carbonise the mass

from the top downwards and from the centre outwards, and Dr. Percy states,* in relating the experiments of Ebelman, that he erected a pile some 30 cubic metres in capacity, containing oak, beech, and fir, in pieces about 2 feet 4 inches in length. "In the centre was the chimney, 10 inches in diameter, extending from the bottom to the top of the pile, and around it the wood was stacked in three layers, one above another, the large pieces being placed in the centre and the small outside. The diameter of the pile was 7 metres (22 feet 11½ inches), and the height about 2 metres (6 feet 7 inches). It was covered all over as usual with soil and breeze. It was lighted in the morning by putting ignited charcoal into the chimney, which was left open for some hours. Vents were made all round the bottom of the pile, and remained open during the whole process to supply air for combustion.

"When the pile was sufficiently ignited, the chimney was filled with small wood and then closed. In the evening the vacant space caused by the burning away of the wood in the chimney was filled with breeze. This was again done next morning. In the course of the day vents were made in the covering of the pile near the top.

"The smoke which escaped from them was white, thick, and copious, but after some hours it became bluish, almost transparent, and much less abundant; then the charcoal burner made fresh vents, about 0·2 metre (8 inches) or 0·25 metre (10 inches) below those above. On the third day, when the vents were

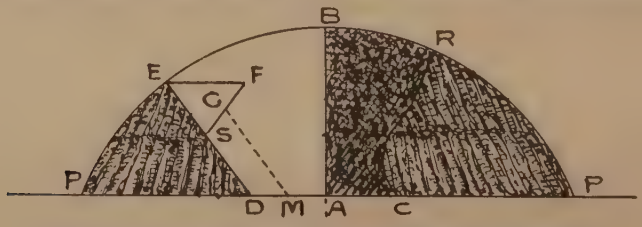


Fig. 52.—Section of Charcoal Heap: Diagram of Process.

1·2 metres (3 feet 11½ inches) above the ground, half of the pile was removed, and the ignited wood and charcoal were extinguished with water. Fig. 52 (Ebelman) shows the condition of the pile at this time, and the gradual course of the charring of wood in circular piles.

"The charcoal was all contained within the space produced by the revolution of the plane E B A D round the axis B A.

"This space represents nearly an inverted truncated cone, of which the radius of the small base next the ground is about 0·4 metre (1 foot 4 inches). In the rest of the pile the wood was unchanged, the pieces being only blackened on the surface by tar, and exhaling an empyreumatic odour; on sawing them across it was evident that they had not even begun to undergo desiccation. The greater part of the charcoal contained within the space E B A D was in pieces placed irregularly as in a heap of charcoal, and without any connection with the surrounding wood. It was only in that part of the pile corresponding to the triangle E F S, and the space included between the line E D and the parallel line G M, by their revolution round B A, that the charcoal remained attached to the wood. The distance between G M and E D was from 0·1 metre (4 inches) to 0·15 metre (6 inches). On each of the pieces of wood included within this space, the passage from perfect charcoal to unchanged wood might

* Percy's "Metallurgy," p. 389 (Fuel).

be traced, the two being separated by partially carbonised, brown wood to the distance of 0·07 metre ($2\frac{3}{4}$ inches) or 0·08 metre (3 inches). The carbonised part of the wood had undergone very sensible contraction. If carbonisation had been allowed to proceed unchecked, the angle P M G would have continued to decrease, until at length the line G M would have coincided with P M, and then all the wood would have been converted into charcoal.

"Hence it is clear that carbonisation in piles is propagated from above downwards, and from the centre to the circumference. The air enters at the bottom of the pile, and finds its way to the space within E D, to which combustion is limited, and the volatile products of carbonisation escape at vents above E F, round the upper part of the pile. It is in the spaces S G M D and E F S that the charcoal last formed remains attached to the wood. But, as the volume of charcoal is considerably less than that of the wood from which it is produced, the spaces between the carbonised parts of the pieces of wood must be considerably greater than between those which remain uncarbonised. But within the space G M A B the charcoal is detached, broken, and irregularly piled in a heap. Hence, the circulation of air should take place most readily where the least resistance is offered—that is, upwards through the space S D M G, with the upper parts of which the vents are in communication."

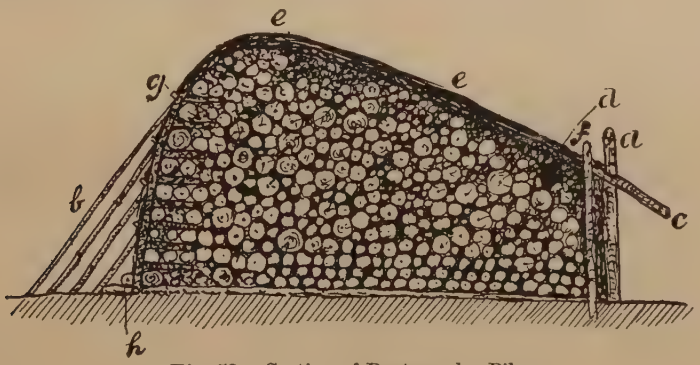


Fig. 53.—Section of Rectangular Pile.

Charcoal Manufacture in Rectangular Piles.—Fig. 53 is a longitudinal vertical section of a rectangular Swedish pile. In the manufacture of charcoal in rectangular piles, a method very much used is due to Swedish charcoal burners, and the following description is from Dr. Percy's version of the process given by Af Uhr and modernised by G. Svedelius, of Stockholm, author of a work on charcoal burning in piles (*Om Koling i Mila*, Stockholm, 1872).*

"The ground on which the pile rests should be solid, dry, even, free from roots and stones, and should slope gradually from one end to the other, about 18 inches in 24 feet.

"The base is sometimes a square of about 19·5 feet side, but more frequently a rectangle of about 19·5 feet across the pile from side to side, and 23·5 or 24·5 feet in the opposite direction—*i.e.*, in that of the slope. Upon the ground, in the direction of the slope, three poles are placed parallel to each other, one in the middle and the other two about 2 feet from the sides of the pile respectively. These poles may be 6 or 7 inches in diameter at one end, and 4 or 5 at the other; the thickest ends should be placed at the upper part

* Percy's "Metallurgy," p. 377 (Fuel).

of the slope. At the low end or foot of the pile are firmly fixed two posts (*f*, fig. 53), inclining somewhat towards the pile, and supported by props on the outside, which are longer than shown at *e*, fig. 53. At this end and all along the bottom, the longest and thinnest pieces of wood are placed crosswise on the three poles forming the foundation.

"The largest pieces should be placed in the centre and towards the high end or back of the pile, where the exposure to heat will be longest. The large and small ends of the pieces should be placed alternately, so that the pile may be level and compact: the interstices between the larger pieces of wood must be filled, from side to side of the pile, with smaller pieces of wood, and the side formed by the ends of the pieces of wood should be even and vertical. It is not necessary to split the wood, for Af. Uhr found that pieces 23 feet long, 2 feet in diameter at one end, and rather more than 1 foot 6 inches at the other, were as thoroughly carbonised in piles of this description as the smaller pieces near them.

"It is hardly necessary to remark that wood of these dimensions is not used for charcoal-burning when it can be more profitably disposed of as timber.

"Hollow pieces of wood must be split, or else filled with small pieces. A horizontal channel or fire-hole (*d*, fig. 53), 6 or 8 inches square, should be left through the pile from side to side, near the low end at about 1 foot from the top, and should be well filled with small wood, very dry, so as to be easily ignitable. At the back the lowermost piece of wood should be let into the three poles underneath it. Into this piece, at about 3 feet from each end, is let, at right angles, a wedge-shaped piece of wood about 3 feet long and 3 or 4 inches thick at the thick end, which is directed outwards towards the back of the pile. Into the wedges a second piece of wood is let transversely, and so wedges and transverse pieces of wood alternate until the pile is completed, as shown in fig. 53. By means of these wedges the transverse pieces of wood, etc., are supported and fixed, and from the bottom to the top of the pile, at this end, is formed a series of parallel openings, which extend inwards as far as the thin ends of the wedges, and which are intended as vents.

"In addition to the two posts, *a*, *a*, in front, there are *a*, *a*, *a*, fig. 54, fixed in the ground on each side of the pile, supported by props.

"The upper surface of the pile is made even, by covering it with a layer, 4 inches thick, of small pieces of wood.

"The larger interstitial spaces in the sides of the pile must be packed with suitable pieces of wood, and the smaller ones with brushwood. The upper surface of the pile is next covered with fir branches or twigs of sufficient thickness to feel soft under foot.

"Over the low end and the upper transverse pieces of wood at the back, the brushwood is bent down, and the depending ends inserted in the interstices of the pile.

"The sides of the pile are also covered thinly with brushwood by sticking the thin ends into the spaces between the pieces of wood and binding the other ends down. The pile is thus prepared to receive its outer carbonaceous or black coating of breeze from previous burnings, mixed in greater or less degree with soil. Chips, twigs, small charcoal, and the like are carefully picked out of the breeze which is to be used for the black coating, for if they are left they might cause irregularity in the admission of air into the pile.

"The black coating is first spread over the brushwood on the top, to a depth of 4 or 5 inches. At the back of the pile a piece of wood (*h*, fig. 53) is let into the projecting ends of the three poles lying on the ground at a distance of

about 6 inches from the wood forming the back. The space thus left is filled with breeze, which is gently pressed down and added until it forms a wall 7 or 8 inches above the piece *h*. Upon this wall is placed a piece of wood (*g*, fig. 53) extending from side to side of the pile. A second course of breeze is built on this piece of wood, and the process is repeated until at length the whole of the back of the pile is well coated. These transverse pieces of wood, *g*, are supported by props (*b*, figs. 53 and 54). On the sides of the pile at the bottom, stones about 5 or 6 inches high are laid at intervals, and on these is built a wall of small or split wood, which is supported by upright posts (*a*. *a*, *a*, fig. 54), which

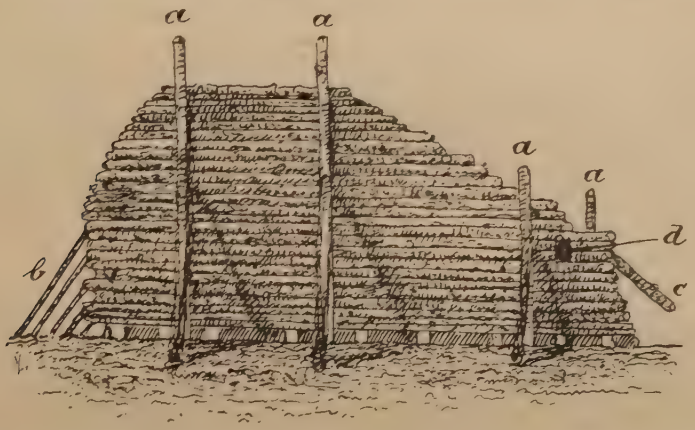


Fig. 54.—Elevation and Part Plan of Rectangular Pile. Copied from Af Uhr's Treatise.

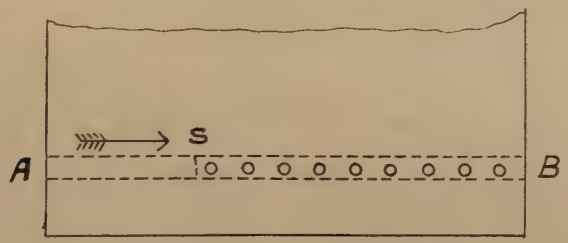


Fig. 54*a*.—Plan of Lower End of Pile.

are firmly stayed, as above mentioned, by the inclined posts, *b*, *b*. There should be a clear space of 5 or 6 inches between the inner side of the wall of wood and the sides of the pile formed by the ends of the wood intended for carbonisation. This space is filled with carefully cleaned breeze simultaneously with the building up of the outer wall of wood; but openings are to be left in the outer walls of wood to the ends of the fire-hole (*d*, figs. 53 and 54) by the insertion and subsequent withdrawal of small pieces of wood. The front of the pile is completed by a wall of wood and a packing of breeze, in the manner above described. Between the stones on the ground at the sides and front, and under the crosspiece of wood, *h*, at the back, suitable vents can be opened round the bottom of the pile Care must be taken to stop any openings in the

angles at the back, formed by the ends of the transverse pieces of wood, which support the cover and the outer side-walls of wood.

"When ready, the pile is lighted through the fire-hole (*d*, figs. 53 and 54) on the side which may happen at the time to be least affected by the wind. When the fire has reached about one-third of the width of the pile, as shown in plan at S, fig. 54, the end of the fire-hole on this side is closed, while the opposite end, where the air for combustion of the small wood in the fire-hole must enter, is left open. Small vents, of about 1 inch in diameter, are then made successively in the cover down to the fire-hole, *d*, in order to draw the fire towards the opposite end, as indicated by the direction of the arrow in the plan of fig. 54, and, when the fire has reached this end, the fire-hole is entirely closed.

"With dry wood it may require a day to light the pile, but with wood which is not dry the lighting may occupy a day and a half or even two days.

"The outline, A B, in fig. 54 is a diagram representing in plan the top of the low end of the pile. The dotted parallel lines indicate the fire-hole, which extends from A to B. The round spots between these lines indicate the openings through the roof or cover, but are shown larger than they are actually made.

"The object should now be to cause the fire to extend equably through the wood along the cover above towards the back, and also downwards to the bottom of the pile. The fire is easily made to extend downwards, by air rising from the bottom of the low end through the pile. To draw the fire towards the back of the pile, some vents are made in a line across the cover, at a distance of 5 or 6 feet in front of the fire—*i.e.*, nearer the high end of the pile. As the fire advances gradually along the cover, and the smoke which issues from the vents becomes light, they must be stopped up, and others made nearer the high end of the pile. When the fire has reached the summit of the pile, vents must be made over the uppermost transverse pieces of wood at the back of the pile; and the whole cover should then be well stamped down, and an additional thickness of about 3 or 4 inches of breeze added to it, to check the passage of gases through it. Carbonisation is to be made to proceed gradually downwards from the cover to the bottom of the pile, by means of the last-mentioned row of vents, which are successively replaced by other rows, lower and lower down the back of the pile, to which air obtains access by means of a row of vents made at this period along the bottom of the back of the pile. Lastly, vents are made at the bottom of the pile along the sides, and when it appears that the lowest stratum of wood has been carbonised all the remaining vents are closed, and the pile is everywhere rendered as impervious to air as possible.

"Wherever the wood feels loose under foot, on walking over the top, it is a sign that carbonisation is completed, and the cover over that part of the pile should then be beaten down and made thicker. Owing to the contraction of the wood by carbonisation, the cover gradually sinks to a certain extent, and this sinking should take place uniformly across the pile, from one end to the other, without the formation of any steep ridge or irregular projections. If the wood is dry when stacked, carbonisation always goes on more easily and better. The vents are made with a shovel through the coating of breeze into the twig covering, and sometimes they are made deeper by means of an iron bar. When the charring has extended throughout the whole pile, the cover is gradually taken off, beginning at the foot, and the charcoal lightly quenched with water. It is then removed to a storehouse, where it remains until winter, when the roads become suitable for its transport to furnaces."

Let the diagram, fig. 55, represent a section of a rectangular pile, and the space B R G A correspond to the section of half the circular pile shown at fig. 51, as shown by the letters B A P. In the circular pile the carbonisation proceeds from the line B A outwards and downwards, and supposing the wood in the space B A M G already reduced to charcoal, and the process active in the space G S D M, the air for combustion circulates upwards, and will do the same in the horizontal pile, but in the circular pile the smoke may escape at vents arranged round the level of E, while in the horizontal pile it escapes at vents across the top at E′, the draught being in the direction of the arrow, fig. 54.

Modifications of this method of charring in piles are mentioned by Dr. Percy as described by Karsten, the difference being in the arrangement of the wood in the pile, which takes the shape of a blunt wedge, the outside being lined with boards behind stakes driven into the ground. When the pile is completed it is lighted at the lower end, and if the process proceeds satisfactorily the charcoal will be drawn first from the lower end. Another modification is described by placing the timber to be charred lengthwise instead of cross-

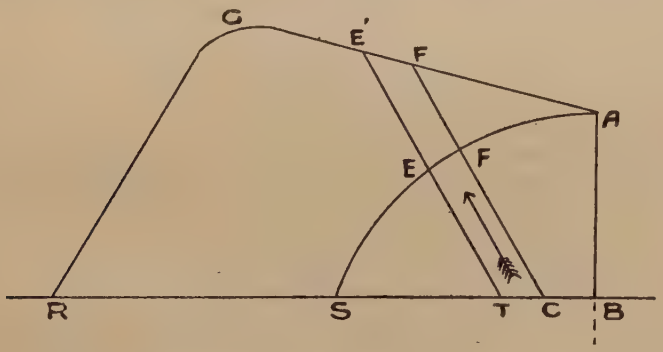


Fig. 55.—Diagram illustrating Theory of Charcoal Burning.

wise in the pile, and logs over 9 inches in diameter are split up. Owing to the direction of the timber the draught naturally follows the interstitial spaces between the pieces and charring is by this means performed more quickly. It may, however, be questioned whether the quality of the charcoal, or the yield in quantity, does not suffer in this method as compared with other methods requiring a much slower operation.

It is stated that the products of distillation may be collected by the insertion of cast-iron pipes at the high end of the pile and connecting these to a condenser.

A method is also described, as practised in China, of making charcoal in pits, a process coming nearer to the modern method of charring in ovens, to be described later.*

Two methods are described, and when the soil is friable or of a sandy nature the charring is performed in pits, but when of a clayey nature, excavations are made and these are arched over. The latter method is generally preferred,

* "De la Fabrication du Charbon de Bois en Chine," par M. Kovanks, Major au corps des Ingénieurs des Mines, St. Petersburg, 1840. Percy's "Metallurgy," p. 385 (Fuel).

and so perfect has the process been rendered by the Chinese that even the small twigs and branches are carbonised without losing their shape or form.

In the first method, the pits are dug out in a circular form, and never attain a depth of more than 6 feet, but are often formed as large as 14 feet in diameter.

The illustration, fig. 56, shows a section and plan of this apparatus or method of charcoal burning. The pit has on one side a chimney E, which is carried from the bottom of the pit up to about 3 or 4 feet above the ground level, and is connected to the pit by a small channel C, about 14 inches long and 4 inches deep.

The chimney is constructed scientifically, its dimensions depending upon

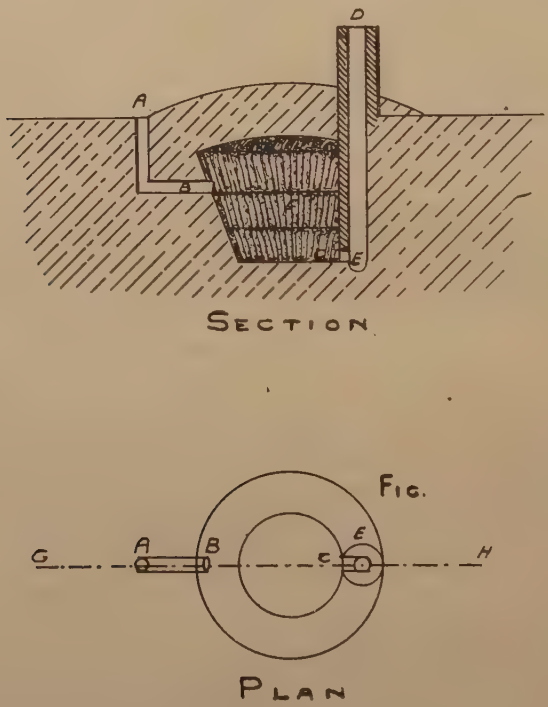


Fig. 56.—Charcoal Pit.

the size of the pit and the amount of wood to be charred. If the diameter is 14 feet, the chimney at the base will be about 14 inches wide, tapering to half this width near the top. Opposite the chimney shaft is an opening B, shown in the illustration, with a vertical continuation to the surface at A, about 4 inches in diameter. The bottom of the pit is usually covered with a bed of dry, small branches, and upon this the wood is piled, as shown in fig. 56, in as close contiguity as possible ; as soon as the pit is filled the wood is covered up with small branches, and then made air-tight with a layer of soil.

The wood is lighted by means of the channel A B, the chimney in the meantime being open, and a draught induced through the pit. If the combustion proceeds too rapidly, producing a large quantity of smoke, the pit is covered up with stones, a small opening only being left to carry on the slow combustion,

enough to carbonise the wood but not to consume it. This is generally left for about five days, when the colour of the smoke changes, becoming light and transparent; all apertures, including the chimney, are now hermetically sealed and made air-tight. The pit is now left for five or six days, when the charcoal is cooled sufficiently to be extracted. It is stated that charcoal made from wood freshly cut loses less in the process than dried wood, 100 lbs. of the former producing from 30 to 35 lbs. of charcoal.

Dr. Percy doubts this yield as compared with European practice, if good black charcoal is produced. But this process conducted in a pit underground involves non-exposure to atmospheric air, as in the process already described of burning in heaps or piles; from this consideration the yield should, therefore, be greater from the method by which the air can be successfully excluded towards the finish of charring, and afterwards, which is the most critical time, when losses may occur from oxidation. While the charcoal is red hot, it has a great affinity for oxygen, and if this element is not completely excluded after the charcoal has been formed losses will certainly occur,

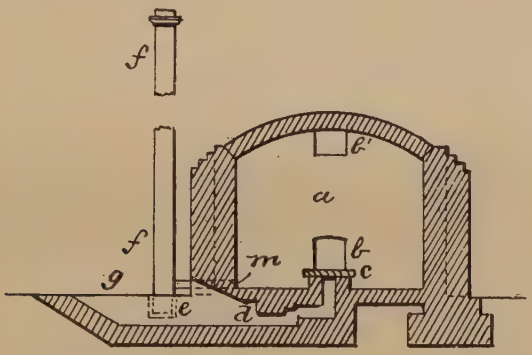


Fig. 57.—Cross Section of Charcoal Oven.

and it is quite possible that as this process is conducted underground, air is less easily accessible to the charcoal than if only protected by a covering of turf and earth above ground. The Chinese, therefore, have what would seem a much better process than the charring in piles of European practice.

The second method of performing this operation in a soil of a clayey nature is conducted in a similar excavation, but has a chamber arched over the top, with a chimney at the side and the opening in the opposite side. The chamber is usually made 4 feet 8 inches in height and 14 feet in width, and has a low door, by which it is charged with the wood, the latter being placed horizontally on the floor and piled up to the roof as close as possible. It is then ignited through the opening opposite the chimney, the doorway in the meantime having been closed up with stones and made air-tight.

As soon as smoke makes its appearance at the orifice where ignition has been started it is almost closed, a small opening being left and the process now carried on as in the other method.

Manufacture of Charcoal in Ovens.—The manufacture of charcoal in ovens as practised in Sweden is described by Dr. Percy from information supplied to him from a large ironworks there. Fig. 57 shows a cross-section, fig. 58

a longitudinal section and a plan of the oven taken from drawings supplied to him; *a*, *a* is the interior of the oven, covered by an arch, supported on side buttressed walls. The oven has openings at *b*, *b* at the bottom in the ends and openings at *b'*, *b'* at the top ends. The bottom openings are used for the purpose of filling the oven with timber as high as is possible, and the charge is completed through the upper openings *b' b'*. As soon as the oven is charged completely, all these openings are closed up securely and sealed. There is a passage made through one side, underground, and underneath through the side wall, terminating in a flue *d* upon which is placed a cast-iron plate *c*; the end of the

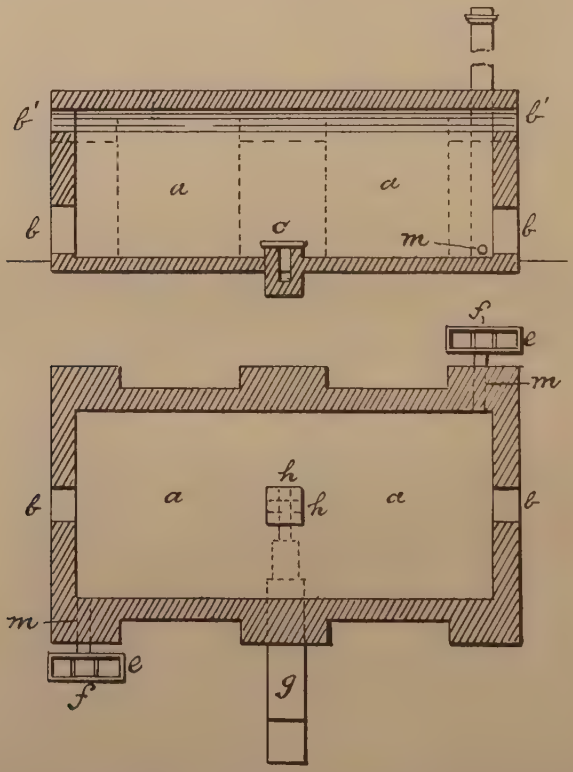


Fig. 58.—Longitudinal Section and Plan of Charcoal Oven.

flue *d* is formed so that the plate has four openings, one on each side of it, as at *h*, *h*, fig. 58. The excavated portion at G serves as an entrance to the fireplace at *d*. When the fire has been lighted in *d*, the channel being first filled with fuel, the fire is communicated immediately to the centre of the chamber, the draught being open through the charge of wood to the chimney stacks, which are formed at two opposite corners of the oven, as shown at *f*, fig. 58. These chimneys are constructed of wooden planks, and stand in wooden troughs *e*, *e*, the connection through the wall being made by a flue pipe, generally of iron, *m*, *m*, provided with dampers, so that when the process of carbonisation is completed it is closed. When the process is complete all openings are completely

closed and clayed up and the oven left to cool, after which the charcoal is discharged. It is stated that charcoal made by this process is not so suitable for refining-hearths, owing to its brittleness, as that made in piles, and that it produces smoke, but if the latter assertion be correct, the charcoal could not have been perfectly burned. The shape of the oven, with reference to the position of the two chimneys, may favour the incomplete burning or carbonisation of the charcoal situated in the ends or corners of the oven opposite to the chimney shafts; another set of chimneys at the opposite corners of the oven would have given a better distribution of the heat, as doubtless some of the wood was under carbonised, for smoke was produced by its combustion in the refining hearth.

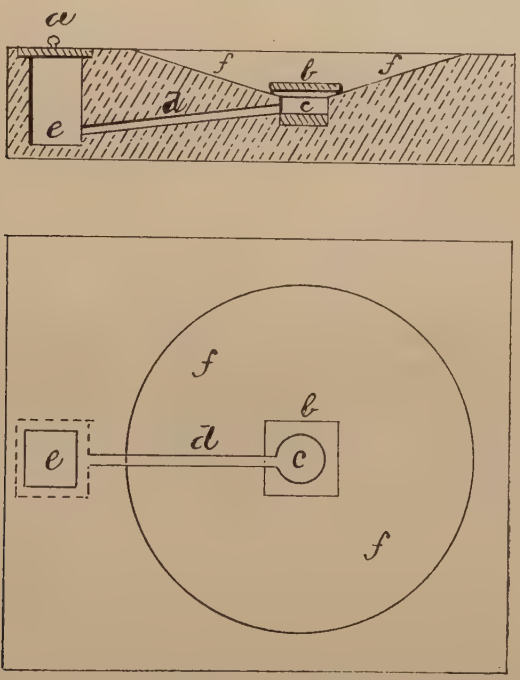


Fig. 59.—Section and Plan of Circular Oven for Charcoal.

Manufacture of Charcoal with Recovery of By-Products.—Karsten describes a process for making charcoal on the large scale and at the same time obtaining by-products from the wood undergoing carbonisation, and fig. 59 shows a vertical section and plan of the arrangement, *f*, *f* being a hollow excavation lined with brickwork at the bottom of which there is formed a small cavity *c* communicating by means of a channel *d* with a receptacle *e*, which is covered with a movable lid *a*. The central cavity *c* is also covered with an iron plate *b*, and openings are formed round this plate communicating with the cavity *c*, so that tar and any liquid may descend through the cavity along the channel and be deposited in the receptacle *e*.

The wood is piled in the usual way on the bed of brickwork; channels, three in number, are formed from the centre to the circumference, about 4½ inches

high, which are filled with charred wood and other fuel. When the pile is completed, the fire is applied to the wood in these channels, the carbonisation being conducted as already described, in circular piles.

The products of combustion condensing on the cooler portions of the wood trickle down to the floor of brickwork and through the channel to the receptacle; great care has, however, to be taken to see that no air enters the pile through this receptacle and channel.

The amount of by-products produced by such a process cannot be considered economically as satisfactory, since the smoke is allowed to escape freely, and also the tar and pyroligneous acid; only that which may escape evaporation and consumption in a process where combustion takes place in the interior of the pile is utilised.

To get by-products from either wood or coal the process must be conducted out of contact with air, if it is to be successful. Charring or carbonising wood in retorts, with apparatus for conducting, condensing, and collecting the liquid by-products will now be described.

The preparation of charcoal and recovery of by-products is by far a more economical process when conducted in retorts or closed externally fired ovens, both as regards the yield of charcoal and of by-products, than when conducted by any of the processes hitherto described.

The above process described by Karsten, consisting of an excavation in the ground, lined with brickwork, in the form of an inverted truncated cone, as shown in fig. 59 in plan and vertical section. In the centre and at the bottom of the conical bed there is a pit *c*, which is covered with an iron plate *b*. The pit *c* is connected by a channel *d* underground with another pit *e* fitted with an air-tight cover *a*. The wood is piled upon the brickwork *f*, *f* in the usual way of making circular piles, and is fired, the process being conducted in the same manner as charring in piles above ground, but the object here is to drain off the tar and liquid distillate from the wood into the receptacle at *e*. It is stated that care must be taken that no air enters the pile by means of the channel *d*, otherwise the products for which this arrangement is made would be lost, together with a quantity of charcoal.

When, however, the by-products are required to be recovered completely, a retort is necessary, and the process is conducted in a similar manner to the coking of coal with the recovery of its by-products.

The retort may be made of iron or fireclay, and the process may be conducted in horizontal or vertical coke ovens if necessary, but where the recovery consists of wood tar, turpentine, pyroligneous acid, etc., an apparatus as illustrated in fig. 60 is used. A retort, A, is made of iron and built into a furnace W, W, and heated by means of the fire-grate F and the flues surrounding it H, H. This retort is fitted at the top with a tightly fitting cover M, by which the charge of wood is inserted, the finished charcoal being withdrawn through the door at F.

This apparatus is known in Sweden as a thermo-boiler, and one described by Hessel contained about 8 cubic metres of wood. The temperature is rapidly raised at the commencement, by the introduction of steam, under pressure, by the tube G. The tar as it collects is run off through the tube E into the receiver D, and the gases and uncondensed vapours are conducted away by the pipe B through the receiver C, where any liquid is taken up and then falls into D through the pipe N. The vapours that are still uncondensed are then conducted into the condenser O, kept cool by the reservoir of water in P. The condensate is then recovered in another receptacle at R, while the vapours are

conducted back under the fireplace for consumption as fuel. When the operation is completed the charcoal in the boiler is extinguished by means of steam.

By such a process of charring the products gained, besides the charcoal, are impure acetic acid or wood vinegar, a little butyric acid, creosote, a wood spirit, and a thickish wood tar containing paraffins, naphthalene, benzene, toluene; from certain kinds of wood oil of turpentine is obtained. According to Vohl, peat can also be used, 10 cwts. of which yield 3 kilos. of acetic acid and 1·45 of wood spirit.

In the manufacture of acetic acid in France an apparatus similar to that shown in fig. 60 is used, but without the lower tubes—*i.e.*, simply the boiler of iron and the condenser. The boiler, however, is not fixed in the brickwork furnace, but is taken out by means of a crane, and charged with wood through the door at the top; it is then lowered into the furnace, the walls of which

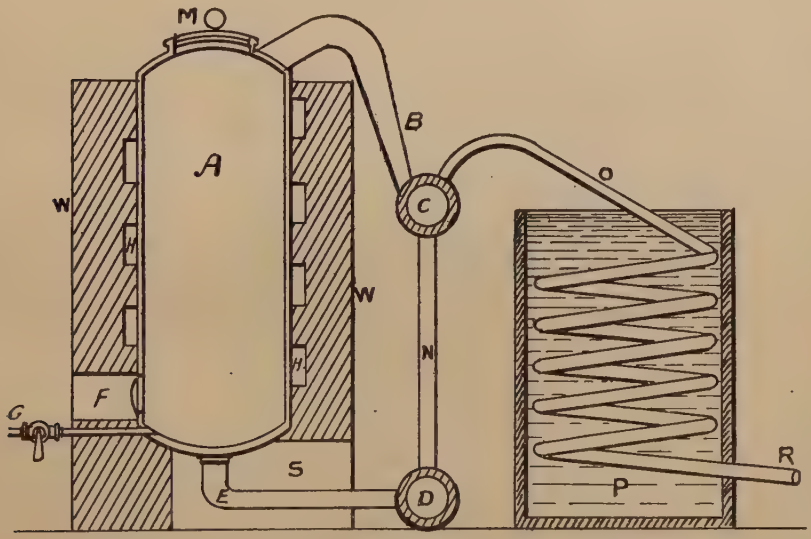


Fig. 60.—Section of Distilling Apparatus for Wood Charcoal.

are a little higher than shown above, so as to cover the boiler completely. The top of the furnace is then covered with a firebrick lid, an opening being left in the side wall for the condenser pipe to protrude, which latter is then connected up to the condenser.

Where the purpose is solely the manufacture of fine charcoal, and where the by-products enumerated above are not required, the process is conducted in an apparatus shown in fig. 61, which is a vertical section through the furnace and retort. This apparatus consists of a furnace heated by means of the fire-grate *c*, and the flues *b*, *b*, surrounding an iron retort, which is fitted with an air-tight door *p* fastened and secured by the screw fastening *m*, *f*, and *n*. Into this iron retort is inserted a smaller retort formed cylindrically with a close-fitting door or cover at one end at *h*, and with the other end formed with perforations for the purpose of allowing the gases and products of distillation to escape. These find their exit ultimately from the outer retort by the tube *e*, which is

usually conducted into the fireplace for the consumption of the combustible gases, tar, etc.

The inner retort or *slip* is usually made of sheet iron and filled with small pieces of the wood selected for the purpose required ; about 1½ cwts. are usually packed in, and the process of converting into charcoal takes about 2 to 3 hours, the attainment of which is known by the gases assuming the reddish-violet tint of burning carbon monoxide at the end of the pipe in the fireplace. The slip is removed from the retort with its contents of charcoal and placed in a box to cool out of contact with air. About 40 lbs. of charcoal are obtained from such a charge, known as "cylinder charcoal," and used principally for the manufacture of gunpowder. For this purpose wood has to be chosen

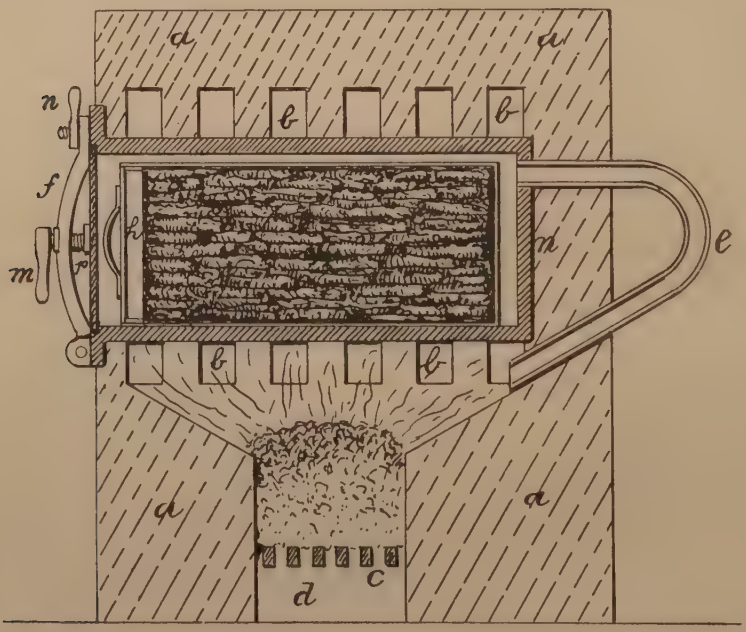


Fig. 61.—Longitudinal Section through Retort for Wood Charcoal.

that leaves as little incombustible matter as possible, and when so employed it is left for about two weeks for the purpose of absorbing moisture, in order to prevent explosions or spontaneous combustion in the subsequent process of grinding to a very fine powder. When the heavy tar has failed to make its exit by the end of the slip and has thus become deposited upon the charcoal, it forms a shining coat on the surface. These pieces are generally known as tar charcoal, and are usually rejected for the manufacture of gunpowder.

The woods generally selected for charcoal for use in gunpowder manufacture are willow, alder, buckthorn (*Rhamnus frangula*), commonly called dogwood, but distinguished from the real dogwood (*cornus*). These woods yield a very light and highly combustible charcoal. The charge of wood is usually dried before it is charged into the slip, because damp wood causes a loss in weight of charcoal made, as the carbon of the wood is oxidised by the action of

the steam upon the incandescent charcoal, the steam being decomposed with the formation of gases which pass away by tube *e*.

The following table shows generally the principal by-products from the distillation of wood, together with the charcoal :—

Wood { *a*. Wood. *b*. Hygroscopic water.

α. Illuminating Gas,
- Acetylene, $C_2 H_2$
- Ethylene, $C_2 H_4$
- Propylene, $C_3 H_6$
- Butylene, $C_4 H_8$
- Benzene, $C_6 H_6$
- Toluene, $C_7 H_8$
- Xylol, $C_8 H_{10}$
- Naphthalene, $C_{10} H_8$
- Carbonic oxide, CO
- Carbonic acid, CO_2
- Methane, CH_4
- Hydrogen, H_2

β. Tar,
- Benzene, $C_6 H_6$
- Toluene, $C_7 H_8$
- Styrolene, $C_8 H_8$
- Naphthalene, $C_{10} H_8$
- Retene, $C_{18} H_{18}$
- Paraffin, $C_{20} H_{42}$ or $C_{22} H_{46}$
- Phenol:
  - Carbolic acid, $C_6 H_6 O$
  - Cresylic acid, $C_7 H_8 O$
  - Phlorylic acid, $C_8 H_{10} O$
- Guaiacol: Oxyphenic acid, $C_6 H_6 O$
- Resin:
  - Creosote: $C_7 H_8 O_2$, $C_8 H_{10} O_2$, $C_9 H_{12} O_2$ — Combination of Oxyphenic acid and homologous acids and methyl.

γ. Wood Vinegar,
- Acetic acid, $C_2 H_4 O_2$
- Propionic acid, $C_3 H_6 O_2$
- Butyric acid, $C_4 H_8 O_2$
- Valerianic acid, $C_9 H_{10} O_2$
- Caproic acid, $C_{10} H_{12} O_2$
- Acetone, $C_3 H_6 O$
- Methyl acetate, $C_3 H_6 O_2$
- Wood spirit, $C H_4 O$
- Phenol, Guaiacol and Resin

δ. Charcoal,
- Carbon, . . 85 per cent.
- Hygroscopic water, 12 „
- Ash, . . . 3 „

The by-products produced by the distillation of wood as they come from the condenser are crude, and have to undergo subsequent processes of purification. The raw wood vinegar is in the form of a dark brown liquid, and may be used in this state for certain purposes, for the preservation of ropes, timber, etc., and in the state of acetate of iron or alumina in the textile industry; also in the preparation of acetic acid, in the manufacture of aniline from nitrobenzene, in making sugar of lead (acetate of lead), and a certain quantity has found its way for the manufacture of table vinegar for domestic use. When this crude vinegar is required to be purified it is distilled from a copper still, the first runnings consisting of a yellow liquid, from which the ordinary raw wood spirit is prepared. The second runnings—that is, the products of the further distillation—produce acetic acid.

The first distillate is lighter than water and consists principally of methyl alcohol, $C H_4 O$ (wood spirit). This substance was first discovered in 1812 by Taylor, and has a specific gravity of 0·814, with a boiling point of 66° C. It resembles ordinary alcohol in many ways, but it does not possess the heat units of an equal weight of ordinary alcohol when burned.

By the complete combustion of alcohol to carbonic acid and water there are developed 7,189 units of heat. By the complete combustion of an equal weight of wood spirit to carbonic acid and water only 5,307 units of heat are developed.

Methyl alcohol is largely employed in the manufacture of methyl bromide and iodide and in the preparation of colours obtained from tar.

The Combustibility of Charcoal.—When charcoal is first obtained, directly after carbonisation, it burns readily, especially so if it can be produced at a red-heat temperature, but as all the hydrocarbons have been expelled in the process of carbonisation it is difficult to light, since it is a very bad heat conductor, but when it is once heated up to the point of ignition and with the free admission of air, it will burn rapidly.

The following table shows the comparative heating effects of various kinds of charcoal, as compared with carbon :— *

	Absol.	Specific.	Pyrom.	1 part of Charcoal reduces of lead.	1 part Charcoal heats water from 0° to 100° C.
Well-burned charcoal, air dry, .	0·97	..	24·50	..	
Well-burned charcoal, quite dry,	0·84	..	23·50	..	
Birch wood, „	..	0·20	..	33·71	
Ash wood, „	..	0·19	..	..	
Red beech wood, „	..	0·18	..	33·57	
Red fir wood, „	..	0·17	..	33·51	
Sycamore wood, „	..	0·16	..	..	
Oak wood, „	..	0·15	..	33·74	
Alder wood, „	..	0·13	..	32·40	
Linden wood, „	..	0·10	..	32·79	
Fir wood, „	..	..	..	33·53	
Willow wood, „	..	..	..	33·49	

On an average 75·7 parts.

The evaporative power of fir-wood charcoal with 10·5 per cent. moisture and 2·7 per cent. of ash amounts to 6·75 kilos.—viz., 1 kilo. of the charcoal will evaporate 6·75 kilos. of water. Charcoal (anhydrous) with 3·02 per cent. ash will evaporate 7·59 kilos. of water. According to Frescenius, the evaporative power of air dry beech wood as compared with torrefied wood (*bois roux*) is as 54·32 : 100.

In the manufacture of charcoal care must be taken to desiccate the wood as thoroughly as possible, because when wood saturated with water is submitted to heat in making charcoal, the portion that is already charred and is red hot is transformed into carbide of hydrogen and C O, and the carbon of these gases, passing away from the retort, is lost. Karsten made some experiments upon various woods in order to ascertain the effect of both low and high temperature, and the following table shows the results obtained, together with those of Stolze and Winkler :— †

* Wagner's "Chemical Technology."

† Muspratt's "Chemistry," p. 35.

TABLE SHOWING YIELD PER CENT. OF CHARCOAL AT HIGH AND LOW TEMPERATURES.

Species of Wood.	By the quick process of charring.		By the slow process of charring.	
	Karsten.		Stolze.	Winkler.
Young Oak,	16·54	25·60	26·1	22·8
Old „	15·91	25·71		
Young Red Beech,	14·87	25·87	24·6	17·8
Old „	14·15	26·15		
Young White Beech,	13·12	25·22	23·8	..
Old „	13·65	26·45		
Young Alder,	14·45	25·65	..	..
Old „	15·30	25·65	..	..
Young Birch,	13·05	25·05	24·4	17·6
Poplar,	..	..	23·8	17·7
Old Birch,	12·20	24·70	24·4	17·6
Birch 100 years old, well preserved,	12·15	25·10	..	..
Young Deal—Pinus Picea D,	14·25	25·25	23·4	20·6
Old „ „	14·05	25·00		
Young Fir—Pinus Abies D,	16·22	27·72	21·5	20·1
Old „ „	15·35	24·75		
Young Pine—Pinus Sylvestris,	15·52	26·07	23·7	..
Old „ „	13·75	25·95		
Lime,	13·30	24·60	22·8	16·2
Ash,	..	..	22·1	19·4
Willow,	..	..	22·2	15·0
Rye Straw,	13·40	24·60	..	..
Fern Straw,	17·00	27·95	..	..
Cane Stems,	14·65	26·45	..	..

In commenting upon these results Muspratt states, "It will be observed at a glance that the advantage of a slow process of carbonisation in regard to the production of charcoal is in some cases double, and is, therefore, so profitable in this respect as to warrant its being resorted to upon all occasions. A slight difference exists in the proportions of charcoal which many of the woods in the foregoing table afford, although the same course was followed in their carbonisation. The probable causes of these variations are, the changes of temperature which are liable to be experienced even within short periods in the course of manufacturing processes, and agreeably to this supposition, the widest range will be found between the results obtained at the high heat, when the variation was more likely to exist, than in those samples charred at a low temperature. Taking the numbers in the second column of Karsten's results as the maximum quantity which it is possible to obtain on the large scale, and comparing them with those which are arrived at by manufacturers who distil wood with the greatest precaution in closed vessels, and who have in view the utilisation of all the products resulting from the operation, this remarkable coincidence will be apparent. The general results obtained by these manufacturers may be expressed thus for 100 parts of wood :—

Charcoal,	28 to 30
Acid and water,	28 to 30
Tar,	7 to 10
Carbonic acid, carbonic oxide, carbide of hydrogen, and uncondensed water,	37 to 30

" If to these numbers the weight of wood necessary to effect the distillation, and which is generally about twelve and a half parts, be added, the result will agree well with what is arrived at in practice in burning for charcoal. In air-dried wood containing about 45 per cent. of carbon this element is distributed in the following manner :—

Charcoal left as residue, ...	30·00
,, combined in the form of acetic acid, . .	0·50
,, ,, in the state of tar, . . .	6·00
,, ,, as carbonaceous gases, . .	3·50
,, required to effect the distillation, . .	5·00
	45·00

" These results agree as closely as can be expected with the numbers given by theoretical calculation, assuming that there is no further disturbance of the elements beyond the union of the oxygen and hydrogen to form water, and the evaporation of this body together with the heating of the remaining charcoal to incipient incandescence, or to about 932° F. Making these conditions the basis of the calculations, it is found, theoretically, that to form water from the elements in 112·5 parts of wood, and to dispel it together with the moisture in combination, which amounts to about sixty-seven and a half parts, the heat developed by the combustion of six parts of charcoal is necessary. Proceeding in the same way, it is found that to bring the residuary charcoal to the above-mentioned temperature, about 0·77 part is required, making in all 6·77 parts. Practically only 5 parts of charcoal are burned to perform this work, but unfortunately much of the carbon is carried away in the gases, so that the last number swells to 8½ or 9 parts of charcoal in the charring of the quantity already named. Even these figures are close enough to those deduced from theory to warrant the inference that in the charring of wood no very considerable improvement towards producing a larger yield of carbon can be made upon the common method by which from 25 to 27 per cent. of the original substance is obtained."

The results of carbonisation at high and low temperatures differ very widely, as is the case with coal treated in a similar manner. In the case of wood, this is shown by the table of results given above. The wood acted upon by Karsten was dried in air, and that of Winkler was desiccated in a hot room, and Stolze torrefied his at 212°.

The theoretical amount of carbon contained in wood that should be obtained upon carbonisation is generally about 40 to 45 per cent., but the most careful operation in closed retorts will not produce more than about 28 per cent. This is accounted for by the reaction of the liberated water, formed at a certain temperature, upon the carbon, forming new combinations rich in carbon, the richest hydrocarbons being expelled first, and these gases consisting of water vapour and carbonic acid, succeeded by carbonic oxide and acetic acid. As the distillation proceeds the oxygen compounds contained in the tar oils are succeeded by the hydrogen series of carbides. Therefore, the more water that can be extracted from the wood prior to its carbonisation the greater will be the yield of charcoal, as it will be seen that water in the wood is the chief cause of loss of charcoal for the reasons given above. According to

Sauvage, who conducted some experiments in making charcoal and torrefied wood, when carbonisation is continued beyond a certain time there is a loss in the weight of charcoal. The results of his experiment are given in the following table :—*

100 Lbs. Wood Charred for	3 hours.	4 hours.	5 hours.	5·5 hours.	6·5 hours.	Mound Charcoal.
Weighed . . .	65·4 lbs.	53 lbs.	47 lbs.	41·5 lbs.	39·1 lbs.	17·2 lbs.
100 cubic feet by a similar treatment measured . .	86 cub. ft.	76 cub. ft.	58 cub. ft.	55 cub. ft.	52 cub. ft.	33 cub. ft.

When the following numbers are considered in connection with the preceding table, the loss sustained in combustible matter will become apparent :—

AMOUNT OF COMBUSTIBLE MATTER CONTAINED IN :—

1 cubic foot of wood, ...		908	parts by weight.
1 „ „ charred during 3 hours, . .		883	„ „
1 „ „ „ „ 4 „ . .		904	„ „
1 „ „ „ „ 5 „ . .		1,133	„ „
1 „ „ „ „ 5·5 „ . .		1,091	„ „
1 „ „ „ „ 6·5 „ . .		1,136	„ „
1 „ of Meiler Charcoal, ...		1,096	„ „

Juncker,† in order to ascertain the amount of charcoal obtainable from different kinds of wood, carried out some experiments. All the woods operated upon by him for this purpose were about 32 years old. The woods were weighed and charred in heaps of the same size.

The same attention as regards time, etc., was observed on each heap. The results were as follows :—

	Centesimally.	
	Charcoal.	Half-charred wood.
Green red beech, cut in May, 1832, ...	19·7	0·6
„ „ „ without bark, . .	23·0	0·3
Dry red beech and oak, two years old, ...	24·0	0·3
Dry oak, two years old, without bark, ...	25·7	0·34
Green oak, cut in May, 1832, ...	22·4	0·3
„ „ „ without bark, . . .	21·2	..
„ „ „ with bark, ...	18·8	1·0
Equal parts of barkless red beech and oak cut in Jan., 1831, carbonised August, 1831, ...	23·4	0·5
Green red beech with bark, charred immediately, . .	12·9	0·3
Green oak, immediately charred, ...	13·5	0·4

The hygroscopic nature of charcoal, or its power to absorb moisture, is dependent upon the degree of heat used in its preparation. Violette carried

* Muspratt's "Chemistry," vol. ii., p. 45.
† Muspratt's "Chemistry," vol. ii., p. 46.

out a series of experiments to ascertain the amounts of moisture absorbed by charcoal distilled at different temperatures, the results being as follows :—*

Temperature of Carbonisation. Deg. F.	Quantity of water absorbed by 100 parts of Charcoal.	Temperature of Carbonisation. Deg. F.	Quantity of water absorbed by 100 parts of Charcoal
302	20·862	554	6·920
320	18·220	572	7·608
338	18·180	590	7·200
356	16·660	608	5·554
374	11·626	626	4·504
392	10·018	644	5·904
410	9·742	662	5·894
428	8·954	810	4·704
446	8·800	1,873	4·676
464	6·666	2,012	4·444
482	7·406	2,232	4·760
500	6·836	2,372	2·224
518	6·306	2,732	2·204
536	7·879		

Charcoal produced at different temperatures exhibits different and peculiar phenomena when subjected to burning. Muspratt relates the following effects :— Charcoal made at low temperatures, say between 302° and 482° F., burns with a long, yellow flame when plunged into alcohol and ignited and then allowed to burn in tranquil air ; it gives off large volumes of smoke, and maintains the temperature of combustion for about 15 minutes. Charcoal made at 482° to 809° F. burns with a clearer flame. That prepared at 809° F. does not burn so well as that prepared at about 662° F., nor does the ignition continue so long. When, however, the carbonisation is effected at higher temperatures, the charcoal, on being introduced into the flame, becomes red hot, does not flame, and is extinguished immediately on withdrawing it, without giving any indication of combustion or leaving any coating of ash. He also gives the following table showing the ignition point of charcoal prepared at different temperatures :—

TABLE SHOWING THE TEMPERATURES AT WHICH CHARCOAL, FROM THE SAME WOOD, PREPARED AT INCREASING TEMPERATURES, BURNS.

Charring Temperature. °F.	Temperature at which the Charcoal takes fire. °F.	Charring Temperature. °F.	Temperature at which the Charcoal takes fire. °F.
500	644	1,873 to 2,732	1,122 to 1,472
518 } 536 }	644 to 680	Charcoal prepared at the point of fusion of the cylinder.	2,282
554 to 662	620 to 698		
8,093	752		

Charcoal in powder ignites at the same temperatures as when solid, but more rapidly and with greater intensity.

* Muspratt's "Chemistry," vol. ii., p. 48.

CHAPTER VI.

CARBONISATION OF COAL.

Primitive Processes—Coking in Piles and Heaps.—Coking or carbonisation of coal doubtless followed, at the first, the same methods and processes that were in use for making wood charcoal, the earliest forms of which were, coking or "charking," in "coke-hearths" or "coke fires"—names given to piles. These were either circular in form, or in the heaps having a long, narrow, rectangular form. Round coal was used in these processes, as *slack* coal was not suitable, no doubt from the presence of a large quantity of small dust coal, which, by filling up the interstices between the larger pieces completely, prevented combustion taking place rapidly enough to carry on the process. At best this was extremely wasteful, a large percentage of the coal being consumed in the process, as may be witnessed by the amount of ash produced.

The piles were constructed of various sizes; that shown in fig. 62 represents

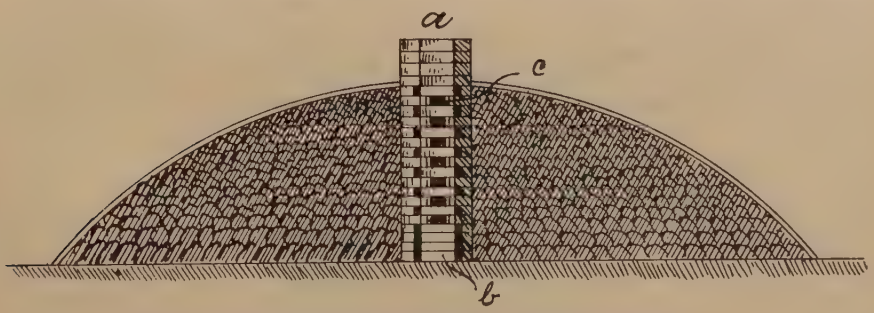


Fig. 62.—Section showing Charring Coal in Circular Heaps.

a circular pile in use in South Staffordshire in 1845. This was built upon a flat, solid bed of dry earth with a chimney *a* constructed of brickwork, in the centre, built dry—that is, without mortar or any binding material—the bricks being bedded one upon the other, with openings *c* left to form flues into the chimney all the way up to the top of the pile, where the coal is heaped. Above this point the chimney is built without openings, and is surmounted with a flat quarry-brick to act as a damper. Sometimes a cast-iron damper in the form of a cylinder with an internal lid was built on the top of the chimney, more effectually to stop the draught, and which was usually filled up with sand.

This central chimney rested on four pillars of brick, *b*, in the smaller piles, and six pillars in the larger ones, which attained a diameter of 3 feet 3 inches outside, the bricks employed being arch-bricks. It seems that only non-caking coal was used in these piles, and for obvious reasons the coal was built up in regular pieces round the central chimney flue, and in some cases the firing commenced at one side near the top, and gradually proceeded downwards throughout the whole heap; in other cases the hot, live coal to kindle the heap

was placed down the chimney and ignition and firing commenced at the bottom and gradually worked upwards.

In the former method the coal was stacked round the chimney, with the smaller coal outwards, and finished on the outside with a layer of wet coke-dust from previous operations, a space being left round the bottom, as in the case of charcoal burning, for the admittance of air.

As the ignition is effected near the top, thick smoke makes its way to the chimney, and soon flames issue from the top of it. The process at first sight seems simple enough, but it required a great deal of skill and attention on the part of the "coke burner" to produce good coke with the least amount of loss, and constant attention to the surface of the pile during carbonisation was necessary, so that when any irregularity occurred in the heating, and undue combustion ensued, this had to be checked by the application of wet coke-dust applied with a spade, this being most frequent during windy weather. When the smoke ceased to escape, which was generally after 5 or 6 days' carbonisation, the whole pile, as well as the space at the bottom, was covered with a layer of wet coke-dust. The damper on the top of the chimney was closed and secured; the heap was then left for 4 or 5 days longer, when it was drawn, having been previously watered. It is stated that such a pile contained about 20 tons of coal, and the yield of coke was about 65 per cent. The coke obtained usually resembled in outward shape the piece of coal from which it was formed.

In the case of igniting the pile at the bottom, according to Mushet, "the fire proceeds upwards, the ignited surface of the exposed coal (which forms a zone never more than 4 or 5 inches broad) is from time to time covered with coke-dust, and a new surface exposed, the dust of which crumbling and falling down protects the ignited surface below it; in this way the fire in 2 or 3 days reaches the upper surface of the pile, the smoke and flame become less, and finally disappear."

It is stated that the practice of placing wet coke-dust on the pile was introduced into the Scotch works about 1801. Mushet also states that a few years later it was introduced into Staffordshire and South Wales, where it was tried and abandoned, on account of the agglomeration of the coal (*coking coal*) by melting and forming a barrier to the draught, which arrested and deranged the proper working of the process. This, coupled with the inevitable expansion of this class of coal when under carbonisation (the swelling up of the coal due to the escape of its gases, which are retarded by the doughy nature of the coal when reaching the coking temperature, whereby the bulk is very much increased), produced in these heaps or piles disturbances on the surface, and formed cracks or fissures admitting air and deranging the process. In Staffordshire, on the other hand, the coal operated upon was dry, non-caking coal, and the coking or charking was practised there long prior to 1805. It was conducted in precisely the same manner as charcoal burning in piles, by covering the pile with leaves, straw or soil, damped; but as this would form a large amount of ash, the process of covering the pile with coke-dust was introduced, and it was generally adopted in preference to the older method.

Coking in Longitudinal Piles.—Dr. Percy* mentions that he saw at the Coalbrook Vale Ironworks a pile which measured 12 feet in length and 3 feet 6 inches in height in the centre, containing about 2 tons 10 cwts. of coal per linear yard. He was informed that the piles varied from 4 to 5 feet in height, in the centre, and from 9 to 12 feet in width at the base.

These piles are different from those circular ones previously described in

* Percy's "Metallurgy," p. 425 (Fuel).

that they have no chimneys. A layer of small coal from 12 to 16 inches thick is placed at the bottom and the larger coal stacked upon it, inclining towards the centre in such a way as to leave channels for air to pass through the inside of the pile, the outside being covered with a layer of small coal. The pile is ignited along the top, combustion proceeding downwards; as the carbonisation proceeds, the coke burner plasters over the surface a layer of wet coke-dust. When the carbonisation is finished this is placed over the entire heap, and it

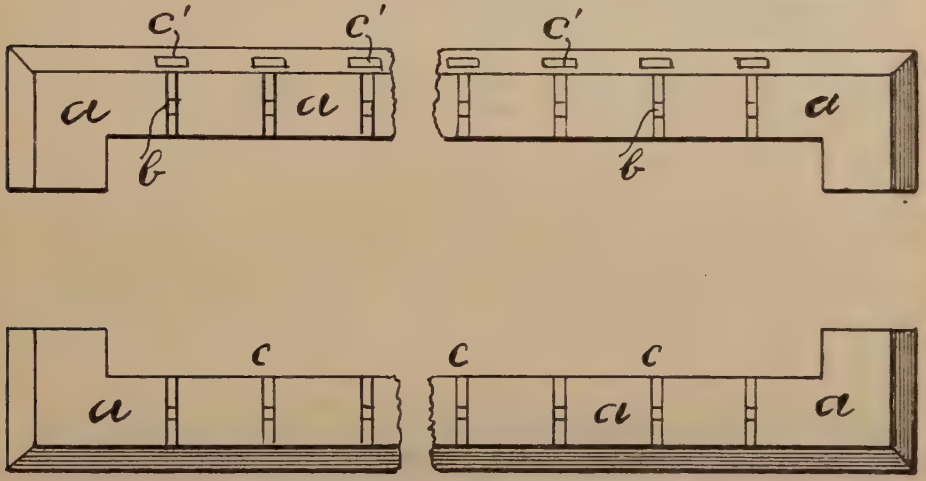


Fig. 63.—Plan of Rectangular Kiln for Charcoal.

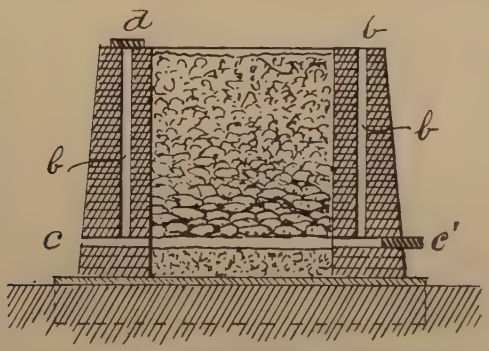


Fig. 64.—Cross-Section of Rectangular Kiln.

is then left for a time. The fire is then extinguished by water thrown over the pile, and the coke withdrawn.

Coking in Rectangular Open Kilns.—This method of coking forms the first connecting link between the charcoal method of coking or charking and the coke-oven process. It consists of a building of brickwork as illustrated in fig. 63, in which *a*, *a* are the outside brick walls, shown on plan, and of which fig. 64 is a cross-section. This arrangement is almost similar to the outside walls of a brick kiln for burning bricks, such as are to be seen in various parts of the country where common bricks are burned.

In the kiln for making coke there are flues constructed in the walls, for the purpose of admitting air, as shown at *b*, *b*, which are vertical flues or chimneys with horizontal flues *c*, *c* in the side walls, about 2 feet apart, underneath them; these flues are placed opposite each other in each of the walls, and provided with a damper as at *c'*, *c'*, another damper being placed over the chimney flues at *d*, fig. 64. The bottom of the kiln is paved with firebrick, and the whole interior of the kiln is lined with firebrick, ordinary bricks not being capable of standing the heat developed during carbonisation.

This process is analogous to the Beehive process, inasmuch as the coal is coked under the pressure of its own weight, but with this very important difference that the heating proceeds from the bottom upwards at the expense of a considerable combustion of coal.

These kilns were erected and worked in Germany, as reported by Brand in 1851, and also at several collieries in this country, upon the same method. A kiln is described as designed by Rogers of Abercorn, who, according to Dr. Percy, communicated to the Institution of Mechanical Engineers in Birmingham a paper on the manufacture of charcoal and coke, in which he says:—"A short time ago a plan was mentioned to the writer as having been used in Westphalia, by which wood was charred in small kilns; as the form of kiln described was quite new to him, it led him to some reflection as to the principle on which it acted, which was found to be so simple and effective that he determined to apply it on a large scale for coking coal. The result has been that in the course of a few months the original idea has so satisfactorily matured and developed, that, instead of coking 6 tons of coal in an oven costing £80, 150 tons of coal are now being coked at once in a kiln costing less than the former single oven." Figs. 63 and 64 are drawings of this oven, which, according to Dr. Percy, was identical with that of the German one described by Brand. The kiln was constructed, as shown on plan, fig. 63, with two parallel walls; the ends were enclosed with a return of the walls, but practically formed the doorway opening. The walls were about 5 feet in height and about 8 feet apart, although kilns were constructed with walls 7 feet 6 inches in height, 14 feet in width, and 90 feet in length, containing 150 tons of coal.

The openings in the walls, forming horizontal flues, and shown at *c*, *c* in figs. 63 and 64, are provided with dampers *c'*, *c'*. These flues are placed opposite each other in the side walls, and from each of these there is a vertical flue or chimney *b*, which can be covered with a damper *d*. According to Brand, the method of charging this kiln in Germany was to close up the end of the kiln with brickwork and fill from the other end with coal slack, watered and stamped down to form a solid stratum about 9 inches thick, or as high as the lower edge of the openings of the horizontal flues *c*, *c* (this may be as high as 2 feet). Pieces of wood, 6 inches in diameter, tapering to 4 inches, were then laid across through the openings in one wall, so as to touch the openings in the opposite wall with the thinnest end of the wood. Wetted coal slack was spread over the wood and pressed well down.

The kiln was then filled up with slack coal which was stamped down and watered at every 6 inches rise. When the kiln was charged completely, the top was covered with a layer of coal dust or loam. The end opening of the kiln was then filled up with brickwork, and the pieces of wood withdrawn very carefully, so as to leave channels through the kiln from flue to flue, any coal that may have fallen in accidentally being carefully raked out. Before lighting this kiln all the dampers on one side were closed, as shown in fig. 63 at *c'*, and a damper placed on the chimneys on the opposite side, as at *d*, while

the horizontal flue underneath was left open, and the vertical chimney flue on the opposite wall also left open. The kiln was now lighted by means of wood introduced into the horizontal flues *c* on the side that they were left open. A current of air was set in motion, carrying the heat and fire straight along the channel formed in the coal to the opposite flue, through which the smoke issued. When the fire had reached the opposite side, the position of the open flues and closed chimneys respectively had to be reversed, this usually occurring after 6 to 8 hours' firing; this was done only, however, when everything had succeeded in proper order, and the fire had proceeded regularly and evenly across the kiln, otherwise subsequent trouble ensued. One of the difficulties experienced was from the weather; under high winds some modification was required in the procedure to counteract too great a draught in local parts. The principal work of the coke burner was keeping the channels clear of ash and fallen pieces of coal which closed them up, and it is stated that when once a channel became choked, it was extremely difficult to get it cleared again. The process of carbonisation took about 8 days to complete. At the end of this time white flame was observed issuing from the chimneys, and the hardness of the charge was indicated by the coke-burner plunging a sharp iron rod down into the charge from the top; should this test prove satisfactory, all the openings were closed for about two days, when the kiln was sufficiently cool to take down the end wall and remove the coke.

The coke was said to be found in large pieces 3 feet long by 1 foot in diameter, the yield being 80 per cent.; but this is very questionable, since the coking heat was dependent upon the consumption of not only the gaseous part of the coal (seldom less than 20 per cent.), but also on the combustion of a considerable quantity of coal in the channels, which were often very much burnt out. These kilns were also installed by the Ebbw Vale Iron Company, but had to be abandoned for this reason.

If the initial heat of the first 12 hours' firing could have been sufficient to have carbonised the whole charge, and if after this period it had been possible to close entirely and seal up the flues and chimneys, economical working might have been possible, as coking proceeded both upward and downward from the horizontal channels. But coal slack is an exceedingly bad conductor of heat, and before the heat capable of carbonising the whole charge was driven through the mass of the charge, the coal surrounding the channels was reduced to ashes. The coke would not be of the same quality throughout; that situated near the channels would be poor, the richest and best coke being found near the upper part of the oven, where the gases would deposit their heavy tarry matters as they made their exit through the coal, and which would ultimately be coked as soon as the heat had penetrated to this part of the kiln.

Dr. Percy states that he visited several ironworks in South Wales, where these kilns had been installed, and on making enquiries as to the results obtained, the manager of one of the works remarked that he considered the process an entire failure; and that, after making allowance for the water in the coke, the yield was "very bad indeed."

Rodgers, on the other hand, had a great opinion of these kilns, stating,* "The new kilns have proved entirely successful; they are already in use at some of the largest ironworks in the kingdom. The great saving in the first cost of oven, economy in working and maintenance, increased yield, and improved quality of coke, will probably soon cause this mode of coking to supersede the others now in use."

* *Proceedings of the Institution of Mechanical Engineers*, 1857, p. 32.

CHAPTER VII.

DEVELOPMENT OF THE BEEHIVE OVEN.

It is somewhat difficult to ascertain with certainty when the first oven of this class was constructed, or when the first ton of coal was coked in it. It is evident that when wood became scarce, and pit coal was coming into general use, experiments were made with coal for the purpose of eliminating the smoke, tar, etc., by the same method then used to convert wood into charcoal. This would be performed in the same manner and in the same apparatus as described previously.

As far back as the year 1620 we have records in the Patent Office of the grant of a patent to Sir William St. John, Sir Giles Mompesson, Sir George Azloffe, Lewes Powell, Walter Vaughan, John Prothero, and Henry Vaughan for 21 years, " To chark or otherwise to converte into charkcole, within our said realms of England and Ireland and dmion of Wales, or anie or eyther of them, all manner of seacole, stonecole, pitcole, earthcole, turf peate, brush flagg, cannell, and all other fewell or combustable matter of what nature or qualetie soever."

No description of the process or of the apparatus or oven is given by which this invention was carried out, but probably a stall or circular pile similar to that used for wood charcoal was employed.

Another patent in 1651 is recorded in a special Act of Parliament. Jeremy Back was granted a patent for making iron with stone-coal, pit-coal, or sea-coal without charking, from which statement it may be inferred that charking or coking was known and practised at that time. Dr. Percy states that the verb " to chark " means to burn to a black cinder, and " to char " is to burn wood to a black cinder ; he also quotes from Plot's " History of Staffordshire," published in 1686, where it is recorded that coal was charred in exactly the same manner as wood, and that the coal thus prepared was called " coak," which was capable of producing as great a heat as charcoal itself. It was used for drying malt, and could generally be employed as a substitute for charcoal, except " for melting, firing, and refining of iron, which," says Plot, " it cannot be brought to doe though attempted by the most skillfull and curious artists." *

In the reign of George III., 1781, a patent was granted to the Earl of Dundonald, numbered 1291, for " a method of extracting or making tar pitch, essential oils, volatile alkali, mineral acids, salts, and cinders from pit coal."

From the description given of this process in the patent, it is difficult to see how any of these by-products could have been obtained from the carbonisation of coal, since the process was conducted in an apparatus or oven where air was admitted. The following is the wording of the specification :—" Now know ye the method I have invented for the extraction of tar, pitch, essential oils, volatile alkalies, mineral acids, and salts, and the making of cinders, from pit coal, consists in admitting the external air to have a passage, or passages, through the vessels or buildings in which the coal from which any of the above

* " Natural History of Staffordshire," by Robert Plot, LL.D. Oxford, 1686, p. 128.

substances are to be distilled is put. Whether by itself or along with limestone, flints, iron ore, bricks, or any other substance, by which means the said coals, after being kindled, are enabled by their own heat and without the assistance of any other fire to throw off in distillation or vapour the tar, oil, alkalies, acids, and salts they contain into receivers or condensing vessels, communicating with the vessels or buildings containing the coals, and at the same time of wasting, calcining or burning any substance that may be mixed with them, and further that, according to what is above set forth and declared, persons who shall extract tar, etc., from pit coal in vessels or buildings, it matters not their shape or size, whereby coals are made to burn without flaming by a regulated admission of external air through different apertures in the buildings, so as by their own heat to throw off the tar, oils, etc., which they contain—persons who do so without my permission are deemed to encroach upon my patent, as the only method used or known until my new discovery was a distillation of coal in closed vessels, where the admission of external air was prevented, and where other fuel or coals were required besides the coals contained in the closed vessels, to produce the heat necessary to pervade the same, and to cause the coals contained therein to throw off the tar, oils, etc., that they contained." He states that he does not think it necessary, "any ways of moment, to subjoin any drawings of the buildings or kilns that may be used according to my new invention for the making of tar, etc., because these buildings may be made either square, circular, or oval, as fancy may direct, the art depending upon the management of the air admitted into the kilns, which can only be acquired by experience."

Doubtless this invention referred to some form of Beehive oven, perhaps the first ever constructed, for making coke, and judging from the title and description in the specification of the invention, it was the first by-product coke-oven process. There is no record as to the practical success of this process, or of its ever being tried on the large scale, but it is obvious that by-products as stated cannot be obtained in an apparatus or oven where there is no source of heat, except from the combustion of the gases from which the by-products are recovered; at the same time, the production of by-products may have been secured by the use of a Beehive oven, worked upon an intermittent method, that is, by the use of dampers in the chimney and by means of flues admitting air, as illustrated in fig. 65.

When the oven was charged, and the coal lighted, the dampers in the flues and those on the chimney stack would be open; a vigorous draught would be induced, the coal would burn rapidly on the surface, consuming the gases and by-products, and producing a high temperature in the upper part of the oven at A, A; when a certain temperature had been attained, the dampers in the air flues, E, would be closed, as well as those in the chimney stack G, and the valve opened at B to the condensers; when this had been done, the flame would instantly stop, and the products of the distillation of the coal, consisting of the gases, tar, etc., would escape unburnt; the tar would be condensed in the condenser and, if the gases were passed through water, the ammonia would be recovered. This would go on until the heat in the oven had so diminished that the process was arrested. The valve to the condenser would then be closed, and the dampers to the chimney stack and in the air flues opened, when the combustion would again commence, the temperature in the oven would rise to the requisite heat, and the process of closing the dampers and opening the valve to the condensers would be repeated, and the recovery of the by-products resumed.

Such a method of intermittent working is simply mentioned here as a possible way of obtaining by-products from coal in an oven by carbonisation of the coal, but as no such procedure is mentioned, and from the patent specification a description of carbonisation is given which can only refer to a process similar to that carried out in an ordinary Beehive oven. At this date it was known that gas could be obtained, and by-products recovered, by the closed-retort process, in which the charge of coal was carbonised by the application of external heat.

About two years later a patent was granted to Jean de Canolle, number 1386, "For making, fabricating, or manufacturing factitious coal for the purpose of fuel by charking or calcining by fire, inflammable or combustible earth in ovens, furnaces, or kilns, with holes for the introduction of air." There is no description

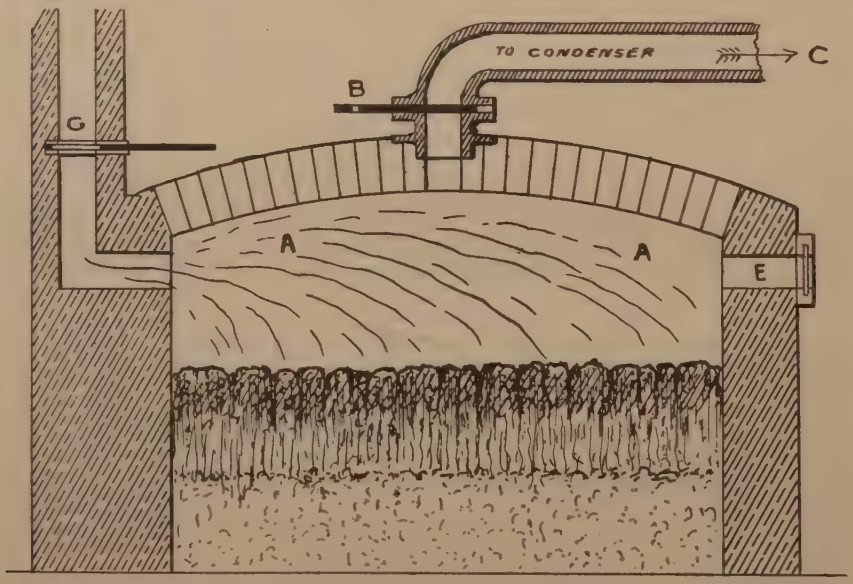


Fig. 65.—Cross-Section of Beehive Oven.

given of the apparatus, and no drawings, but probably a kind of Beehive oven was used.

It is well on in the nineteenth century before we meet with any descriptive matter in a patent, with drawings of the construction of ovens and apparatus for the purpose of making coke from coal. In the year 1838 a patent was granted to Frederick Neville for "an improved method or process of manufacturing coke, whereby the sal ammoniac, bitumen, gases, and other residuous products of coal are at the same time separately collected, and the heat employed in the process is applied to other useful purposes."

The drawings and specification show a Beehive type of oven wherein the gases are consumed in the same manner and the heat obtained as in an ordinary Beehive oven, but above the charge of coal are inserted several retorts, wherein coal is distilled and the by-products obtained. This is simply a combination of the Beehive oven with the closed retort, using the top heat of the Beehive oven to heat the retorts.

In the following year, 1839, a patent, No. 8071, was granted to **John Walker,** for " certain improvements in coke ovens."

By the description and drawings it is evident that attention at this time was being directed to the recovery, or attempted recovery, for further heating

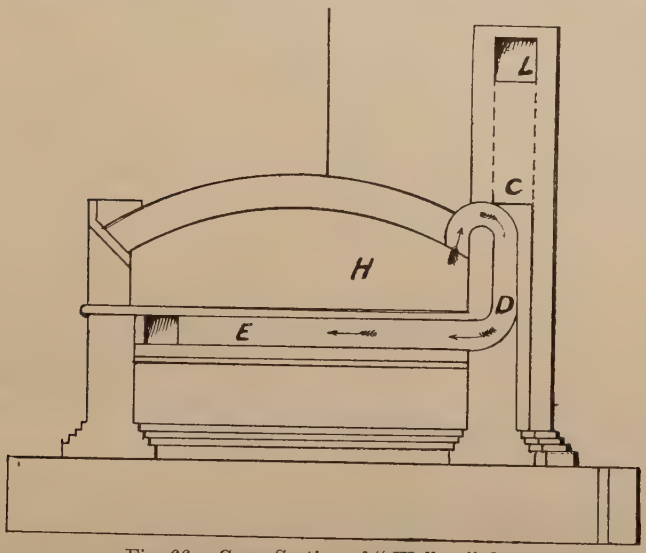


Fig. 66.—Cross-Section of " Walker " Oven.

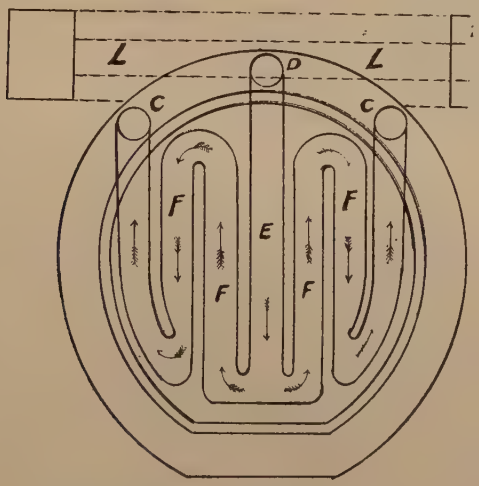


Fig. 67.—Plan of " Walker " Oven.

of the oven, of the waste heat, usually finding its way up the chimney; and to expediting further the carbonisation of the lower portion of the charge in the oven. We have here a very clear drawing of a Beehive oven, which is of a circular form. The interior, H, is filled with coal; the products of the distillation are collected through the flue D (fig. 66), and descend, entering the sole of the oven by flue E (fig. 67); then a zig-zag course, F, is pursued to both right and

left hand under the floor of the oven, and finally exit is made by the flues, C, C, into the horizontal collecting flue, L, to the chimney.

During the period 1838-1850 several patents were granted for improvements in connection with the carbonisation of coal in Beehive ovens, most of which were for economy in working, utilising the waste heat for raising steam, etc., and for heating the lower part of the oven by the same means as described above in the reference to Walker's patent.

In the year 1852 **William Newton** made an attempt to obtain by-products from a Beehive oven, the process being conducted by the ordinary method of carbonisation, that is, by the heat generated due to the internal combustion of the gases and coal contained in the oven. To accomplish this he employed a " pump or aspirator " to draw off the gases " when the draft was insufficient," but when the " draft was sufficient " he used a receptacle containing any

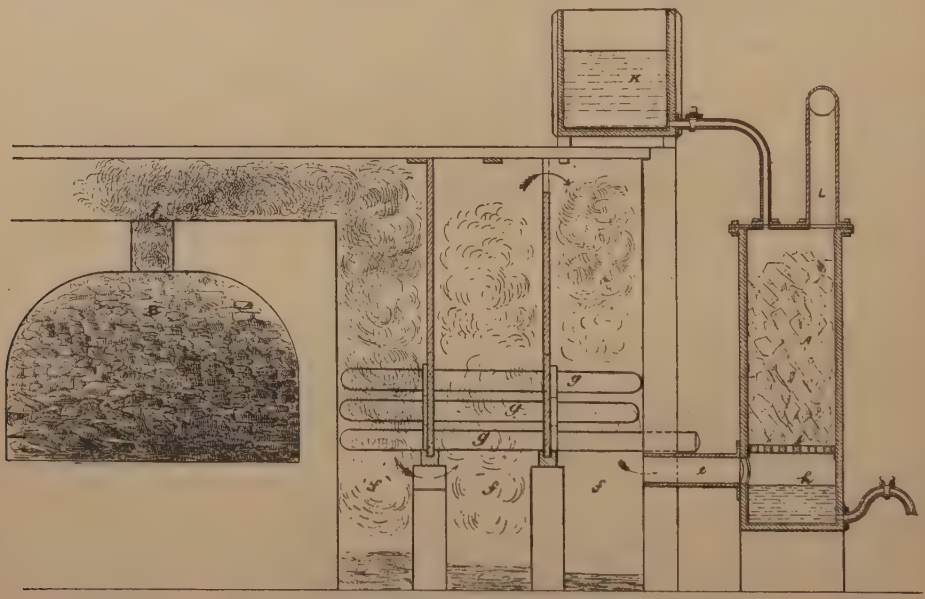


Fig. 68.—Section through " Newton's " Coke Oven.

substance which would absorb the ammonia when the gases were made to pass through it. The substances that he used were stated to be acids, salts, or any substances that would absorb ammonia ; they were contained in the receptacle on a kind of sieve, shown at A, fig. 68. The coal is carbonised in the oven B, the gases are conducted away by means of the flue *f*, and in their passage they are cooled by the " refrigerator," *g*, *g*, before entering the pipe, *e*, under the perforated tray or sieve *b*; the gases are supposed to have deposited their tar in the bottom of the cooling chambers, *f*, *f*, *f*, containing the " refrigerator." The receptacle with the perforated bottom is made of lead or stone, and pieces of hard coke or pumice stone are piled on it at A. Sulphuric acid diluted with water is placed in a tank K, which is made to discharge over the coke or pumice stone, and is collected in the vessel *h*, the acidulated water taking up the ammonia from the gas that passes through the apparatus to the exit L ; the ammoniacal water is drawn off by the syphon cock on the tank *h*.

This invention and patent of Newton's is important, as showing the tendency at this date towards the manufacture of foundry coke, and saving the by-products, as distinguished from the manufacture of gas with by-products—ammonia, tar, benzol, and an inferior coke.

That Newton failed is obvious from a careful survey of the drawings and specification, and due to the fact that the by-products, such as ammonia, tar, benzol, etc., cannot be obtained from gases that have undergone combustion, and converted from the ordinary combustible gases, such as are the products of carbonisation in closed retorts or chambers, into non-combustible gases, water vapour, and soot.

The inventor points out these facts in his specification, stating that the oven is an open one ; the gases he wishes to condense are the products of combustion of the hydrocarbons, produced in the ordinary process of coke-making by the Beehive process, and he states that *soot* is produced and deposited in his condenser.

The only by-products, such as ammonia, that he would be able to condense by such a process would be simply those which had escaped decomposition in the oven, and would certainly never compensate him for his trouble.

With regard to his criticism of the process then practised of making illuminating gas and obtaining the by-products, and his pointing out that the coke that is produced by this process is inferior, he was stating a fact which is incontrovertible, even at this present time ; he points out also that the coke produced in the Beehive oven was superior. This matter will be alluded to later on, and reasons given why this is so, and upon similar lines why the coke produced in narrow quick-operating ovens is also inferior to Beehive coke.

At the same time, it must not be inferred from what Newton states in his specification that by the extraction of by-products the coke was deteriorated. He says, " It seems to be a *sine qua non* that to obtain good coke the oven should not be closed, and the process must in no degree resemble a distilling operation."

The extraction and recovery of by-products in no way deteriorates the quality of the coke, but the method employed to obtain the by-products may very seriously impair the quality of the coke. There are also other factors to be taken into consideration when a comparison is made between coke produced in a Beehive oven, and known as foundry coke, and coke produced as a by-product in the manufacture of lighting gas ; and attention to these factors is often not sufficiently observed in making comparisons. In the manufacture of metallurgical foundry coke, the very best coal, free as possible from ash, sulphur, and phosphorus, is absolutely essential ; whereas in the manufacture of lighting gas any kind of coal will do that will give a large amount of gas of good quality, the coke produced being a secondary consideration, and therefore often containing excessive quantities of ash, besides sulphur, etc., which wholly unfit it for many uses, where these substances have to be avoided.

There are other factors, among which are the time occupied in coking, the condition of the coal in the oven during carbonisation, pressure, bulk, etc., all altering the ultimate product of the coking operation referred to in Chapter V., " Theory of Coking."

One of the disadvantages of the carbonisation of coal in the Beehive oven by the ordinary process of internal combustion of the gases in the oven, for the purpose of obtaining the necessary heat to carry on the process, is the combustion and total destruction and loss of a certain amount of coal, on the surface of the charge, which is exposed to the flame, and the oxidising effect

of the air admitted into the oven. The losses from this source are often very serious, and in the most economically conducted methods are considerable. For the prevention of these losses, a patent was granted to **Claude Laurent Victor Maurice** in the year 1855, B.P. 881. In his specification he describes his improvements. Fig. 69 shows a section of his oven, the principal feature of which he states to be the introduction of air into the oven between the charge of coal and the vault of the roof, in the form of ascending jets, as at *b*, *b* and *d*, *d* in the figure, " for the purpose of burning the gases given off from the coal during the process of carbonisation in the oven." The air supply enters the oven by means of the channels G, which encircle the roof of the oven so that the air when delivered through the nozzles *b* and *d* is pre-heated in its passage through the channel G; upon the entrances to this channel there are valves for the regulation of the supply of air.

The sides of the oven are formed with a curve near the floor, for the purpose of preventing the coal in the lowest angle of the oven from being improperly carbonised.

The oven is charged with coal through a door in the front, and through

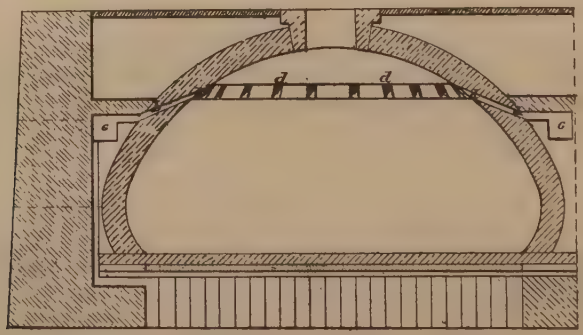


Fig. 69.—Section through " Maurice " Coke Oven.

which the coke is extracted. The products of combustion pass away through the centre of the roof.

One of the earliest attempts to make Beehive coke, and obtain the by-products by a practical method, is recorded in the patent dated 1856, B.P. 514, and granted to **C. A. de Fonbonne,** who combined several Beehive ovens, worked them alternately, and used the gas after extracting the by-products for lighting purposes. There is no record as to the results obtained by this method, or upon what scale the process was conducted, but judging from the specification and drawings of the patent herewith reproduced, it is quite possible that it may have met with entire success, because in this instance dependence for the heat necessary for the conducting of the process of carbonisation is not on the combustion of the gases in the interior of the oven, but on a well thought-out method of arrangement of the ovens together. A set of four ovens are constructed back to back, as shown in fig. 70, and heated by means of a series of flues, A, beneath the sole of the oven, C, C, and communicating with a vertical flue E, by means of another flue, B, constructed within the walls of the oven. A passage, F, in the roof of each oven is provided with a removable cover G, and the upward extension of this passage is closed with a fireclay slab H, and communicates with the central flue E. The passage, F,

serves not only as a conduit for the hot gases from the oven during the first part of the coking process, but also as a charging hole. Pipes, K, convey the gas and ammoniacal and other by-products to a central hydraulic main, L, containing liquid, and provided with an hydraulic valve, M, for regulating the pressure, and another hydraulic valve for controlling the flow of gas to the gas holder. In a modified arrangement, a small auxiliary coke oven is situated between the main ovens. The ovens are first heated to a good coking heat, by opening the charging door in the roof, so that communication is given for a draught to the chimney; when this has been accomplished, the opening is closed and luted. After the charge has been placed into the ovens in succession, the flues passing under the ovens are put into communication with the first oven by opening the valve or cover in the upward passage, so that the gases given off are burned under the adjacent ovens. The hydraulic main and the gas

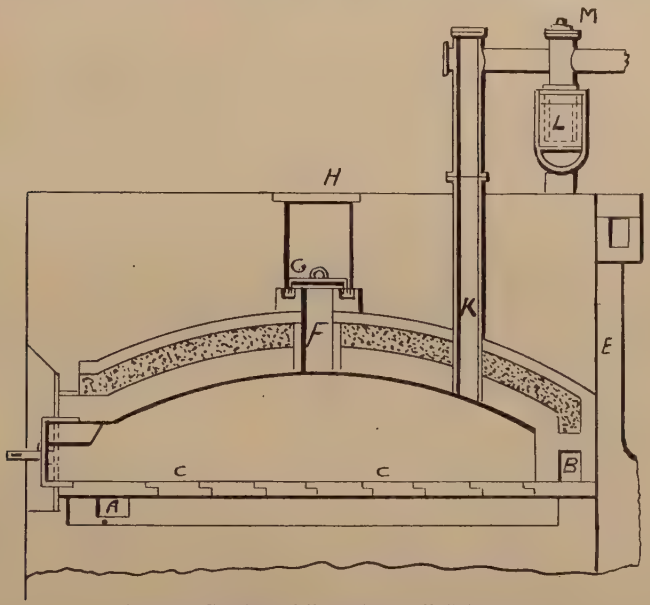


Fig. 70.—Section of " Fonbonne " Coke Oven.

pipe leading to it from the closed ovens are put into communication with the apparatus shown in fig. 71, which consists of an aspirator or exhauster, by means of the hydraulic valve M (fig. 70).

This apparatus comprises a reciprocating bell or piston C, the lower part of which dips under water in the annular space between two concentric cylinders A, B. The bell, C, slides freely along a pipe J, which is secured to the outer cylinder, and connected to the upper part of a water vessel D, and the latter dips beneath the surface of water contained in a vessel E. A pipe, I, communicating with the gas-holder, is attached to the water vessel E, and a pipe, F, connected to the ovens, dips beneath the surface of the water in vessel D.

As all the gas passed through the hydraulic main was used for lighting purposes, that required for heating the ovens was obtained as above stated, by means of keeping one of the ovens, or the auxiliary oven, for the production of gas for this purpose; it is, therefore, very questionable if this process could

be kept up for a long enough time, and to supply sufficient gas to heat the adjacent ovens, so that the carbonisation of the coal in them could be properly performed.

The whole arrangement was elaborate, and could be worked, but not economically; the necessary heat for carbonisation was precarious, and unless some modification in the method of working was adopted, such as alternating the ovens to produce the heating gas, it is difficult to see how it could be worked on a practical scale. The ovens are very low in the roof and wide, exposing a large surface of coal to the action of the heating flues, under the sole of the oven; and this is the one feature in this process whereby it might be possible to produce coke in it; of course, it is quite obvious that there are difficulties to be overcome in such a process. Whether these were mastered, and coke and lighting gas produced, is not recorded, but it is the first serious attempt to produce Beehive coke, and also obtain lighting gas and its by-products.

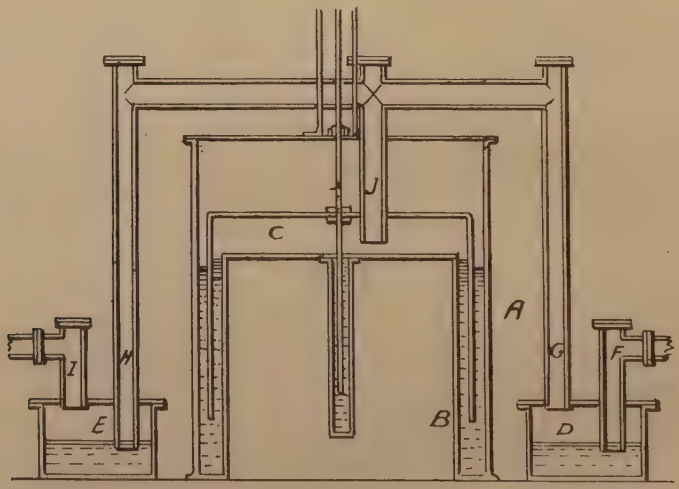


Fig. 71.—Section of Gas Apparatus for "Fonbonne" Coke Oven.

In 1860 an invention of Henry Eaton, of Nantes, in France, was communicated to **John Paddon, M.B.,** and William Lowther, in South Wales, who applied for a patent, and one was granted to them, and numbered 1290. This invention had for its object "improvements in coke ovens," and consisted of an arrangement of about a dozen ovens arranged radially around a central stack. The intention of this invention was to save in the cost of construction, because such an arrangement requires less brickwork as compared with the ordinary construction; the claim of the inventor to a greater yield and better quality of coke, as compared with the ordinary Beehive oven, may be open to question, as there is nothing in the specification or the drawings accompanying it to warrant an improvement in this direction, unless that the conservation of heat in the central part of the oven re-acted on the charge by developing a higher temperature than could be possible in the ordinary Beehive oven; and this is quite possible, but judging from the shape of the ovens, narrowing towards the back, where most of the heat would be concentrated, the best coke would be found in this locality, while that produced in the front of the oven

would not be so good, because the draught to the chimney is towards the back of the oven, while the front is simply heated by radiation from the back portion, and exposed to the chilling effect of the door and outside wall at the end containing the bulk of the charge. This oven could be very economically constructed, and in the practical working of it there would be less waste of heat than in the single Beehive type; the ovens are worked alternately, that is, one is emptied and charged while those on either side are still working, so that the side walls, as well as the back wall, never experience that amount of cooling as is inevitable in the ordinary single oven; the fresh charge would, therefore, be ignited sooner, and the carbonisation finished sooner under these circumstances.

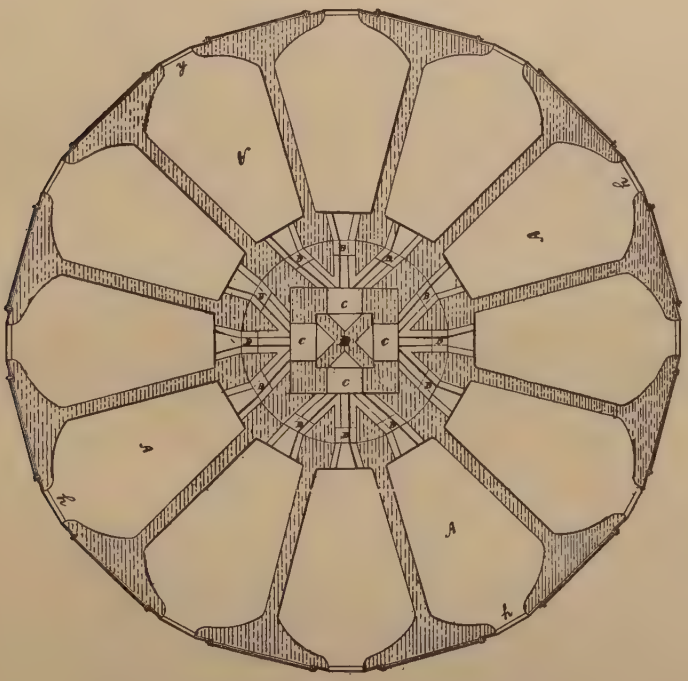


Fig. 72.—Plan of "Paddon" Circular Coke Oven.

Fig. 72 shows a plan of this oven. A, A are the coking chambers, arranged around the central chimney stack B. C, C, C are the flues conducting the products of combustion into the stack from each oven. These ovens are charged by means of the doors *h*, *h*, and the coke when finished is thereby extracted; an inlet for air is provided by means of a movable plate, D, situated over each chimney flue. This, no doubt, is in the wrong place, as the gases given off during the coking period would thus be fed with air in the flues, the result being to heat or melt down the chimney stack. The main entrance for air, however, would be by the charging door, but this is stated to be closed during the whole operation.

A patent applied for in the year 1863 by Richard A. Brooman on behalf of **Charles Claude Pernolet,** to whom a patent was granted, B.P. 1954, for "improvements in coke ovens," marks the period when the modern by-product

oven was being slowly developed, or evolved, out of the Beehive oven; and this patent shows how carbonisation of the coal was effected with saving of the gas and by-products, returning the gas to heat the oven, and keeping the

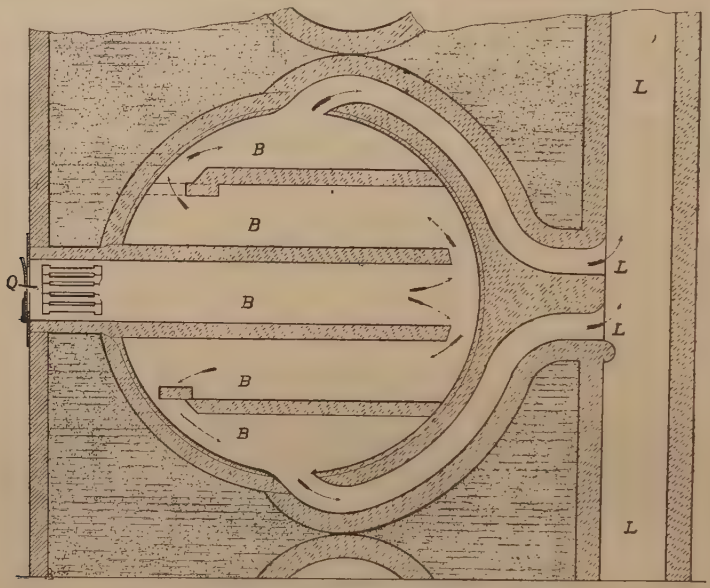


Fig. 73.—Plan of " Pernolet " Beehive Oven.

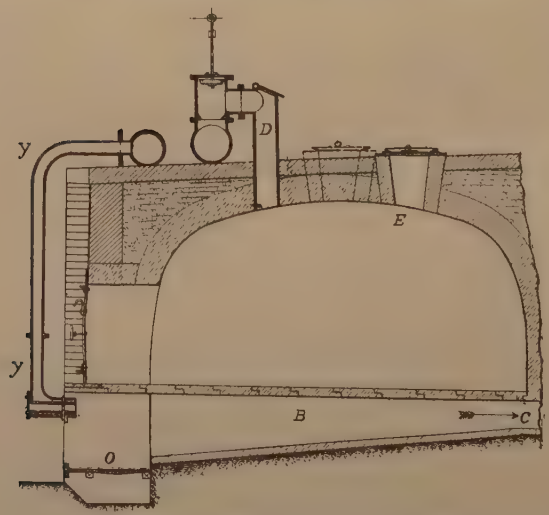


Fig. 74.—Vertical Section of " Pernolet " Beehive Oven.

oven during the process air-tight. This was very ingeniously accomplished by means of an auxiliary fire under the oven. Fig. 73 is a plan of one of these ovens; fig. 74 is a vertical section. The oven is of the Beehive ordinary type,

but is fired from below by the grate O, the products of combustion passing along the heating flues, B, in a zig-zag direction on either side of the grate, and then entering the flue through C to the chimney at L. The gas given off during carbonisation is collected by means of the pipe D, and is passed through condensers to extract the tar and ammonia; the stripped gas is then brought back, either by means of an exhauster, or by chimney draught, to the fireplace through the pipes *y*, *y*. Where the gas is burned along with the coal in the grate, the oven is fed with coal by the inlet in the roof E and the coke is withdrawn by the door in front.

In another chapter of this work, which deals with the by-product horizontal coke oven, this inventor will be referred to as patenting in the previous year, 1862, his horizontal coke oven (for saving the by-products), and fired in a similar manner to the oven described above, by means of an auxiliary grate, together with the gas produced by the carbonisation of the coal in this and the adjacent ovens, after extraction of the by-products. Pernolet, therefore, seems to have been one of the pioneers of the modern method of carbonisation of coal, extracting the by-products and using the gas for heating the ovens, discharging the coke, etc. This process was tried on a large scale by Messrs. Bell Bros., and the results were published by Mr. A. L. Stevenson; quoting Dr. Percy* :—"Not fewer than thirty-six ovens of different shapes and sizes, on Pernolet's system, were tried; but the round or Beehive shape, about 11 feet in diameter, was found to be the best, as it is alleged to be also for the old system of coking, because we are informed that such an oven affords the least possible side coke, greatest concentration of heat, with the least tendency to wear itself out by contraction and expansion due to its frequent cooling and re-heating. The ovens were fitted with iron doors carefully luted with clay, so that no atmospheric air could enter. The volatile products of carbonisation escaped through a cast-iron pipe inserted in the dome of the oven, and passed thence through a long range of similar pipes into condensers, also consisting of a series of similar pipes, each 40 feet long and 1 foot 9 inches in diameter. These pipes to the number of five were fixed horizontally at short intervals above each other, and there were three series of pipes, side by side, or fifteen in all, in what is termed a block.

"This system of pipes communicated with a tower filled with coke, 13 feet high and 4 feet in diameter (inside measure), from which proceeded a horizontal main pipe connected by descending branch pipes with tar wells underneath, each 14 feet 7·5 inches long, 10 feet wide, and 12 feet deep (inside measure), and communicating with a number of ovens. There were two such condensing systems, as above described, for the whole series of ovens. The volatile products of carbonisation in their course from the ovens deposited tar and ammoniacal liquor, which ran into the tar-wells. Under the ovens, only refuse small coal was burned."

Carbonisation, it will be seen, proceeds from below upwards, and, according to Stevenson, the uppermost coal is liable to become what he terms "roasted," and incapable of yielding good coke.

When caking coal is exposed to a temperature of about 300° C. for a certain time, it does not on being subsequently heated to redness produce a firmly coherent coke; and roasting the coal, under the circumstances above mentioned, might be supposed to mean depriving it of its caking property by heating it at too low a temperature at first. What Stevenson means is doubtless that if coal is exposed to a temperature of about 300° C. for a sufficiently long

* *Transactions of the North of England Institute of Mining and Mechanical Engineering*, 1873.

time, so that the hydrocarbons and tarry bodies are volatilised, it loses its coking propensities, and in this he is correct; to prevent this, he states that domes of different heights were tried, and the best yield was obtained from the large round oven, the dome of which was 1 foot 10 inches higher than that of the other ovens. The height of the roof thus reduced the temperature on the surface of the coal. "The yield from the 36 ovens in one week was 249·42 tons of coke, from 367·87 tons of coal, or nearly 68 per cent.; tar (assumed to be anhydrous) 2·4 per cent., and ammoniacal liquor 5·2 per cent. were obtained; but, in addition there was 3½ per cent. of refuse coke, termed "black ends," which was burned on the grates under the ovens, and the loss estimated at 2½ per cent. exclusive of 18 per cent. of gas, conveyed into the fireplace under the ovens. During one period of five months, from 7,591 tons of coal, 70,676 gallons of ammoniacal liquor were obtained, which yielded 14 tons of sulphate of ammonia, or 0·185 ton per 100 tons of coal.

The cost of making the coke was not very much more than by the common oven; the separation of the black ends, superintending the gas arrangements, and attending to the firing of the grates, amounted to 3 pence per ton of coke. The Pernolet system was, however, abandoned by Messrs. Bell Bros., notwithstanding the apparently satisfactory results above reported; the reasons given were that the coke was inferior in quality, and the greater cost of maintenance of the ovens. Stevenson says of these ovens, "The coke under ordinary circumstances was soft and showed a large number of 'black ends,' which alone was sufficient to condemn the process; but for two years or more every trouble was taken, and every possible condition of oven was tried, to make a reasonably good coke, and yet avoid an expensive outlay for repairs; with what success may be seen, when it is stated that on an average each oven was out for repairs during a period of six weeks in one year. Indeed, every four months each and every oven required a thorough repair. The flue walls were built of gannister brick (*i.e.*, Dinas bricks), and these, by the intensity of the heat, gave way, and had to be hacked out piecemeal; the alternative was this, make a good or fair coke and burn the oven down in a very short time, or save the oven and make soft coke.

The late Isaac Lowthian Bell, of the firm of Bell Bros., in 1874 gave Dr. Percy the following memorandum regarding the Pernolet oven:—

"In reference to the ovens we erected for obtaining coke by close distillation, I find the yield was about 64 tons of coke from every 100 tons of coal employed. In addition to this we obtained close on 6 gallons of tar per ton of coal treated in the ovens, along with a certain quantity of ammoniacal liquor, of which we have no very accurate account. The yield of coke I consider fully 5 per cent. better than in the ordinary ovens in which the evolved gases are burned inside the ovens, instead of outside, as happens in the oven in question. This and the tar are no doubt important items; but the expense of manufacturing the brick-work and general increase of labour, etc., went far to absorb all the gain in these respects. There is a second disadvantage which I have found to attend more or less all ovens from which a better yield of coke is obtained from the coal—namely, inferiority of the product for iron-smelting purposes.

"It is generally allowed by smelters that hard coke is best suited for these purposes, and I have sought to explain this in my published investigations by the greater power of hard over soft coke for resisting at elevated temperatures the action of carbonic acid in the higher region of the blast furnace. It is clear that if carbonic acid resulting from the action of carbonic oxide or sesquioxide of iron is reduced to carbonic oxide by contact with carbon, you

not only have a cooling action set up, but carbon, which otherwise would reach the hearth is volatilised, where it renders no service. Now, so far as my observations enable me to judge, there is less of this soft coke in that manufactured in the ordinary oven than in those more refined structures.

"As a consequence, and somewhat against my inclination, I have been led to return to the old-fashioned plan, although its use is attended with a waste of fuel. Against this loss, however, we may now set the application of the heated gases, which formerly escaped into the air, or at all events were not utilised for obtaining steam for the general purposes of the colliery."

Stevenson also states that a range of 120 Pernolet ovens was erected and worked by the Wigan Coal and Iron Company with by-product plant, operated by exhausters, part of the gas being used for illuminating purposes and part being returned to heat the ovens, but, contrary to Stevenson's theory, the flues were carried over the top of the oven. The ovens were 11 feet in diameter, and took a charge of 5 tons of washed small coal. The yield was 60 per cent., which was stated to be good for the coal of the district.

Dr. Percy, commenting upon this conflicting evidence as to the working of the Pernolet oven, states, "It should stand as a warning to persons not to be led away by representations of inventors, and also of distinguished practical men concerning the value of alleged improvements."

There is no doubt that the weakness of the Pernolet oven lies in the method of firing it from beneath, by means of coal; if gas firing had been installed, and this burned with heated air, the results would have been different regarding the amount of repairs required. Gas-firing is clean, but when coal is used, and that of an inferior quality, probably with a high ash content, and containing a good percentage of iron pyrites, alkalies, etc., the brickwork suffers terribly by the fluxing action of these solvents upon the silica of the brick, and the very high local temperature that would prevail in the firegrate. It is stated that the bricks used were gannister from Dinas, that is, silica bricks, a splendid brick for standing high temperatures, with gas-firing, but a worse brick could not possibly have been chosen for use with coal-firing, because of the fluxing action above mentioned; they were exposed to the draught entering the furnace through the firing door. With such a brick the ash of the coal would make it run down into clinker, which is difficult to remove from the walls without serious damage.

A neutral brick, that is, one where the silica contents are neutralised by alumina or some other refractory substance of like resisting nature to the corrosive action of the ash of the coal, does not necessitate so frequent repairs; but under all conditions, where the fuel is poor and the ash-content high and of a fluxing nature, brickwork exposed to the high temperature of the walls of the firegrate will not stand up, and frequent repairs are necessary.

In comparison with the internal combustion Beehive oven, Mr. Lowthian Bell was quite right, the repairs would be practically nil, as the firing or heating of this oven is gaseous, and consequently there is no trouble with any ash or clinker or fluxing of brickwork, and further, the heating is direct on to the coal undergoing carbonisation, whereas in the Pernolet process the heat has to be driven through brickwork, before it reaches the coal, necessitating a very much higher temperature in the fireplace and flues, a stronger draught, and the close proximity of the clinkering ash of the fuel to the grate, besides the volatile dust adhering to the bricks of the flues, containing fluxing material which would also soften the silica bricks near the fireplace and cause their decay.

A further development of the Beehive oven towards the modern horizontal

oven is shown in the invention of **W. C. Stobart,** who in 1864 proposed to construct Beehive ovens in a row and to heat the side-walls with the products of combustion of the gases given off during the process of carbonisation. Fig. 75 shows a cross-section through these ovens; the gases pass by channels in the back walls of the ovens B, and near the bottom of the side walls enter the

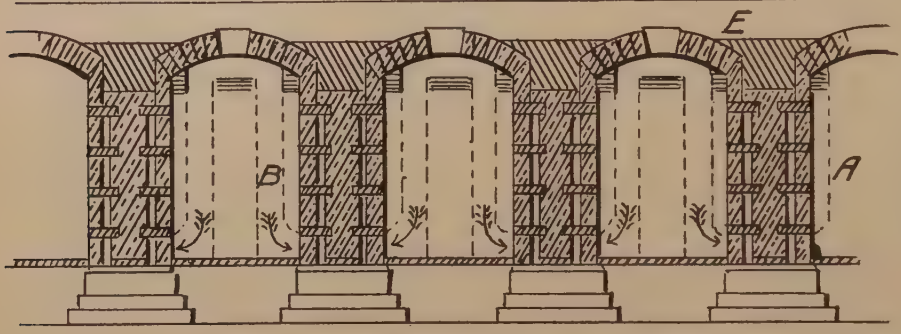


Fig. 75.—Cross-Section of " Stobart " Coke Oven.

horizontal heating flues, A, as indicated by the arrows, and following a zig-zag course ascend the walls and finally issue into the flue, E, to the chimney.

About this time, in 1865, another important step was taken in the development of the Beehive oven by **Messrs. Breckon and Dixon;** the latter was for many years associated with Messrs. Pease & Partners' colliery and coke works, and many of the improvements in the Beehive ovens, and the first introduction

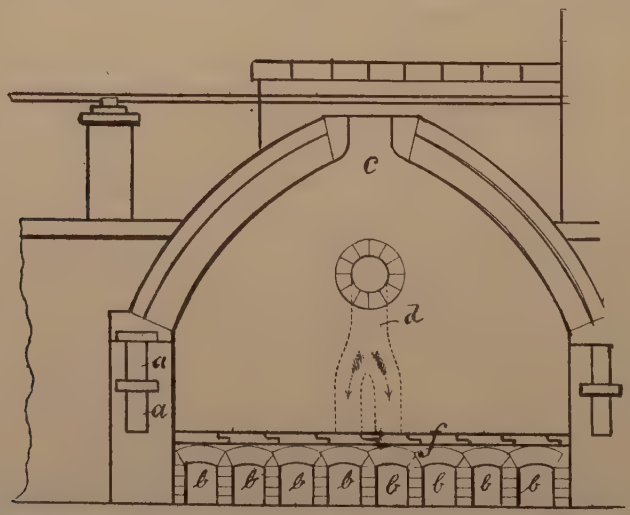


Fig. 76.—Vertical Section of " Breckon and Dixon " Coke Oven.

of the horizontal by-product coke ovens into these works, was due in a great measure to him. The ovens are constructed in a row back to back; the gases from the carbonisation of the coal are drawn off from the coking chamber, fig. 76, by the chimney draught down two flues, *d*, at the rear of the ovens;

then they pass in a zig-zag course on each side of the centre of the oven floor, *f*, as shown in fig. 77, in the direction of the arrows, by means of flues *b*, *b*, then round the walls by flues *a*, *a*, fig. 76, to the chimney; a modification in the arrangement of the flues under the oven floor is proposed, but the design shows

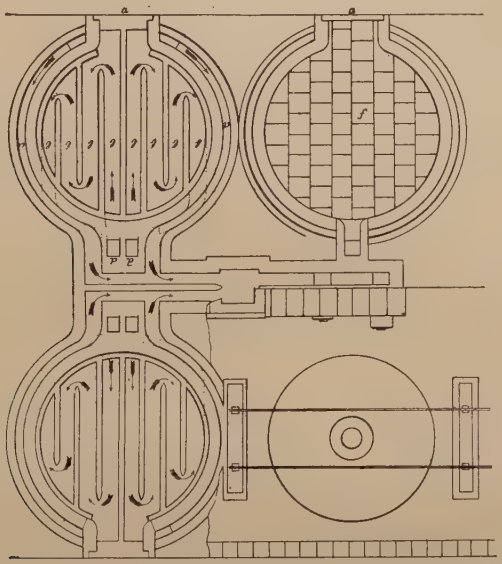


Fig. 77.—Four Sectional Plans of " Breckon and Dixon " Coke Oven.

the tendency in coke oven practice to have the heat surrounding the walls as well as on the bottom of the oven.

No further improvement appears to have been made in the development of the Beehive ovens until 1873, when **J. Bustard** made the improvement in coke ovens of this type as shown in fig. 78, where the ovens are built in rows, back to back, the coal being fed in at the top by trucks, M; the gases given off

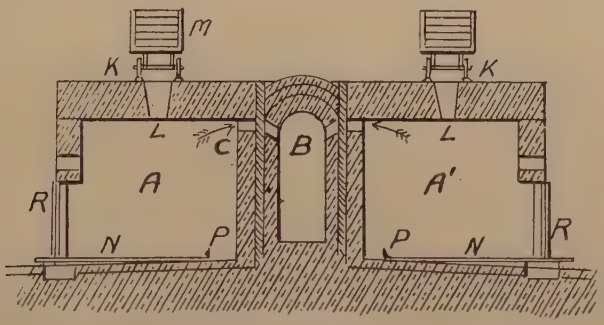


Fig. 78.—Vertical Section of " Bustard " Coke Oven.

are consumed in the oven, the waste heat being carried away by a central flue, B, running between the rows of ovens, and used by conducting them through or under boilers for raising steam. It is most interesting to note that this oven is the one which has survived until the present day, numbers of this design being

still at work in Durham and Northumberland; a kind of grid is inserted on the floor N, P, upon which the coke rests, so that it may be dragged out of the oven without much breakage.

The next development that became a departure from the ordinary Beehive methods of coking was the proposition of **John Jamieson** in 1882, B.P. 1947, in which he endeavours to secure the by-products from the Beehive type of oven. Fig. 79 is a cross-section through a row of these ovens; the coal charge in each of the three ovens, A, B, C, is indicated by cross-hatched lines; the darker portion shows the coke already formed, the lighter shade the original coal. The pipes are laid into the bottom of the oven, the orifice being protected by a fireclay slab; these pipes are for the purpose of drawing off the gas from the lower portion of the oven, thus avoiding the products of combustion in the upper part. The gas is taken away to the condensing apparatus, B, B, fig. 79.

The proposals are, that the best hard metallurgical coke is made in the Beehive type of oven, in the ordinary way, by heating the charge of coal by internal combustion of the gases, within the oven, and above the charge. Obviously Jamieson overlooked the fact that with such methods of carbonisation a considerable amount of the coal on the surface of the charge is burned, and lost, besides the gases that are consumed. The most important proposal

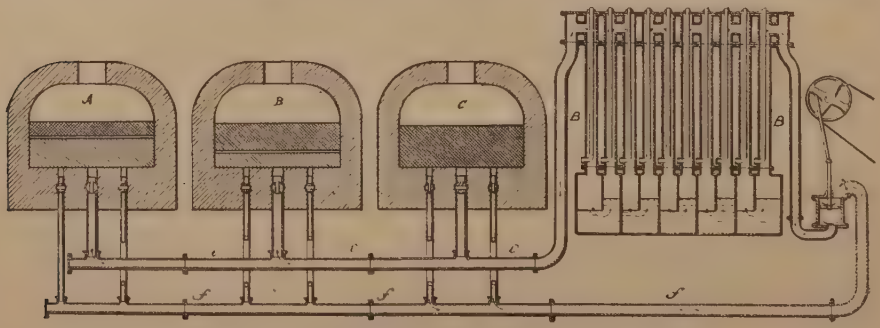


Fig. 79.—Vertical Section of "Jamieson" Coke Oven.

he makes is in the method he adopts for extracting the gases from the oven during the carbonisation, bringing out the important fact very clearly that there is a marked division between the coke already carbonised and the uncoked coal. He says (quoting from the specification), "The dividing lines between the single and double-shaded lines in the charge represent the imaginary position of a stratum of coal which has become more or less agglomerated by heat, and which forms a diaphragm more or less tenacious and resistant to the passage of gas, or air, as hereinbefore mentioned." This is a fact that has too often been ignored by designers of coking plant, and which Jamieson himself seems to have underestimated in his proposals to return to the oven liquid tar, by the pipes *f, f*, fig. 79. The effect of this would be at once to form a solid layer, at the bottom of the oven, of hard, dense pitch, which would be absolutely impervious to the further passage of either liquid tar or gas; apart from this, the proposal to return the gas by the pipes, *e, e*, to the oven is a good one, from the point of view of that time, for supplying heat to procure a very high temperature in the oven, for the purpose of consolidating and perfecting the coke, and for making the hard quality coke that he had set out to make at the beginning; but, as to the proposition he claims of enriching the coke by the deposit of hydrocarbons, that is not quite clear; if, as he states, he withdraws

the gases from the under part of the oven, through the coal, the gases liberated from the upper semi-hot region of distillation carry a considerable amount of heavy hydrocarbons. As the temperature at which distillation proceeds in the region of distillation, in a Beehive oven, by the process of heating from the top, involves what may be termed a "low-temperature carbonisation," heavy tarry oils will be given off in large quantity; but as these heavy tarry bodies are not allowed to make their exit with the gas, freely, as would be the case in the manufacture of lighting gas, or low-temperature distillation in retorts, but have to be drawn through a considerable bulk of raw cool coal, the latter acts as a first-class condenser, and very little tar will be procured; any liquid hydrocarbons will take the form of heavy oil, and not until the process of carbonisation has reached the lower region of the oven will tar be procured. Upon these considerations, there cannot be very much tar at disposal for the purpose of enriching the coke, since it has already been condensed in the coal, and even supposing there was a good supply of tar, it would not be an easy matter to force this material up through the incandescent coke, for the reasons given above, of its forming a local layer of pitch at the bottom of the oven.

With regard to the proposal to supply gas which has passed through the exhauster and condenser, and from which the ammonia has been extracted, this gas would by the above consideration be very poor in hydrocarbons, having parted with them, first, in the filtering process, while passing downwards through the cool stratum of uncoked coal; and then, secondly, by passing through the water condenser shown in the apparatus B, B; so that any enrichment of the coke from the passage of these gases would be very small, and would be confined to the fissures between the blocks of already-formed coke. The erroneous idea generally held, that the passage of gases holding and even saturated with heavy hydrocarbons can enrich, by their deposition of carbon, the interior coke cells, cannot be maintained. These hydrocarbons suspended in gases can only be deposited in the uncoked coal by passing through it, because of the fact that when coal is once coked the cell structure is closed, and the only openings that are available for the passage of gases are in the cracks made by contraction; on the other hand, if it were possible for the gases containing hydrocarbons to obtain admission to the cells, it would only be under exceptional circumstances, such as great pressure, which in the instance under review would be impossible. During the process of carbonisation, the coke soon after it is formed begins to shrink, due to the continued application of heat and the loss of gaseous matter, so that large cracks are developed, mostly in a vertical direction, in the Beehive oven. These cracks or fissures would form channels for the passage of gases from the lower portions of the charge, and the gases following the line of least resistance would naturally flow along these cracks, and would not, therefore, penetrate the substance of the coke.

Should the opposite theory be the case, and the access of gases to the inner cell structure of the coke be as easy as some imagine, it would be an exceedingly simple matter to deposit all the tarry bodies on the coke; and what is more important, it would open the door to the de-sulphurisation of metallurgical coke, by blowing through it high-pressure steam; but, as it is well known that steam cannot penetrate the cell structures for this purpose, it is quite evident that gases, at the ordinary atmospheric pressure, or even above it, will not be able to do so; therefore, by this process, no doubt, very hard first-class coke was made, but it would be subject to the losses experienced in the internal combustion oven. A saving, doubtless, in this direction may have been made by the combustion of the gas returned to the oven, but this could not have

been very much, as it is extremely difficult to cause gas to burn on the surface of incandescent coke, and at the same time prevent the combustion of the coke.

A greater economy could have been made by using the gas for other purposes, and not returning it to the oven. The gain in weight of coke produced by this process over the ordinary process was by extracting from beneath the charge the gases, thus drawing them downwards through the cool coal, and thereby condensing the heavy tarry matters which form the best coke, since they contain no ash; the accumulation of this condensed tar in the coal would consequently bring up the percentage of coke obtained.

In the practical working of the Jamieson process there were difficulties experienced, and one of them was in connection with the working of a battery of ovens for different stages of carbonisation, whereby gases would be given off at different temperatures; whilst those ovens that had been recently charged were discharging rich gases, those nearing completion would be discharging poor gases; the temperature of the former gas would be low, whilst the temperature of the latter would be very high; this would cause considerable trouble if these gases were allowed to come in contact, and the hot gas would prevent the proper working of the pipes, etc. This is quite apparent from another patent granted to this inventor subsequently, in 1884, No. 14,551, in which he admits these defects, and makes proposals for the purpose of remedying them.

Yet a further patent was granted to him for further modifications to get over some of the difficulties in carrying out the process, in 1888, B.P. 13,329.

The next important development in connection with the carbonisation of coal by the Beehive process is described in a patent granted to Messrs. Thomas Frederick Victor Carl Otto and Dr. C. Otto & Company of Dalhausen au der Ruhr, in Germany, and has for its object the working of Beehive ovens, and obtaining the by-products, and the further development of heating the ovens by means of gas burned by heated air, whereby economies are claimed over the existing methods, due to the fact that higher temperatures can be acquired with less consumption of gas or coal, and the time occupied in the process would be shortened. The process is described in connection with the regenerative principle of Siemens for heating the air by means of the waste heat from the ovens; this principle was proposed by Siemens in a patent granted to him for a coking process, in 1863, numbered 972, and which will be referred to again in dealing with forms of coke ovens other than Beehive ovens. The patent granted to **Messrs. Otto** in 1886, and numbered 5522, for this combination with the Beehive oven, will now be described.

It is apparent from these proposals that coke oven gas, after it has been cooled and the by-products extracted, requires heated air for its perfect combustion. Otto proposes to apply the regenerative principle to the Beehive oven, for extraneously heating the floor of the oven, and designs a range of ovens together with an elaborate system of regenerators for the pre-heating of the air. Fig. 80 shows a cross-section, and fig. 81 a plan of coke oven designed on this principle. It is stated that either single- or double-chambered regenerators may be used; in figs. 80 and 81 single-chambered regenerators are shown. The method of working these Beehive ovens is to heat the floor of the ovens by the gas given off during the carbonisation of the coal in the ovens *b*, *b*. The gas is drawn off through the pipe in the roof G, G, and after it has been stripped of its by-products, ammonia and tar, it is brought back in the pipes, P, P, to the flues under the ovens; the air for the combustion of the gas is pre-heated in the regenerators R, R, and brought therefrom by

means of tubes to the combustion chambers under the ovens where it meets the gas. The products of combustion are carried in a circular zig-zag course through flues in the base of the oven, shown at F, F in fig. 81, whence they pass by means of the conduits, *l*, *l*, to the regenerators, giving up their heat, and thence

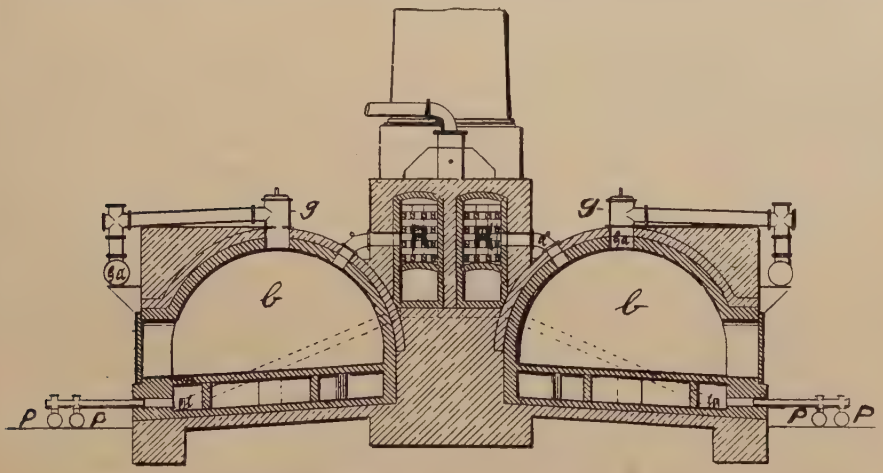


Fig. 80.—Vertical Section of " Otto " Coke Oven.

by the flue, *a*, to the chimney stack. Means are provided for changing the current, that is, for reversing the direction of the waste heat gases, and the incoming cold air for regeneration.

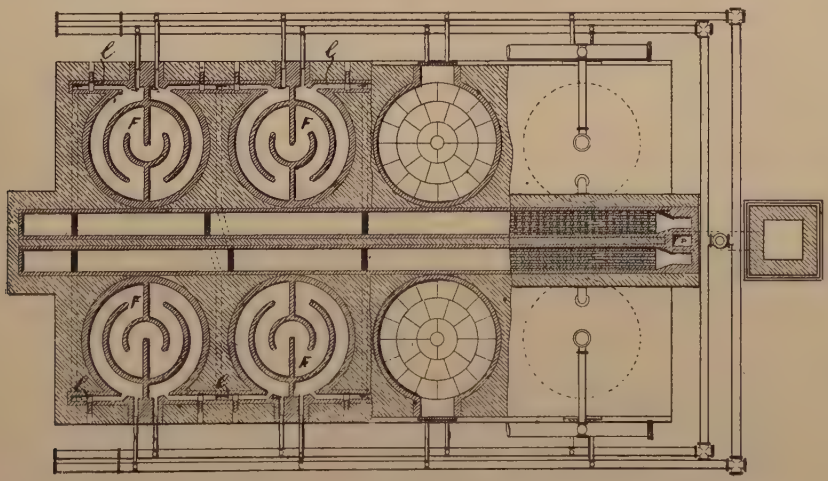


Fig. 81.—Three Sectional Plans of " Otto " Coke Oven.

The carbonisation of coal in a Beehive oven is from the modern standpoint a wasteful process ; 15 to 20 per cent. is usually the loss in weight occurring in this process, as compared with the modern by-product method of carbonisation ; this loss is due to the consumption of the coal and the tarry matter in

the gas in generating the heat necessary to carry on the process, to which may be added the loss of the gas, tar, benzol, and ammonia. Some of the processes described above have lessened these losses to a certain extent, but where competition with the modern by-product oven exists, none of them can hold their own for a moment.

The modern horizontal coke oven, however, cannot coke all classes of coking coals, and, due to this fact, there are at present at work thousands of Beehive ovens. The high fat coals that swell up on heating cannot be coked in the horizontal oven; they have been tried, but, as they swell up to such an extent that the gas pipes are stopped up, causing serious derangement in the working of the ovens, this method of carbonisation has had to be abandoned in favour of the older method.

A process invented by the author, some years ago, for the treatment of coal of this description, and which was successfully tested near Glasgow, fulfils all the necessary requirements in this direction. The coal is allowed to develop its swelling up in a vertical direction, but owing to the pressure of the high column of coal (30 feet) this swelling is curtailed, and instead of a soft, spongy coke, some of the densest and hardest coke has been made in it, from coals of the Lanarkshire coalfield, otherwise not cokable in the ordinary horizontal by-product coke oven. Not only was this coal coked, but all the by-products were also obtained, and when a sample charge of Durham coking coal was carbonised in this oven dense hard coke was produced, heavier than either Beehive coke or by-product horizontal-oven coke; also from 5 to 6 per cent. more coke was obtained from this coal than was usually made in the modern horizontal by-product oven; this oven will be fully described in another chapter describing vertical ovens.

Since the development of the horizontal by-product coke oven for making coke quicker and cheaper, the Beehive process has practically ceased making any further progress beyond what has been shown above, and the number of Beehive ovens treating coal suitable to that process are year by year gradually diminishing.

Under the more modern ideas of carbonisation and economical working, the coking or charring of coal in heaps, and the Beehive oven with internal combustion of the coal, will soon be out of date, and become simply a matter of history. The extent of the depletion of the British coalfields demands processes of carbonisation in which all waste must be avoided, and these must be of quite a different character in the near future from either charring in heaps or Beehive practice. Every ounce of material, whether in the form of coke, gas, benzol, tar, ammonia, etc., must be accounted for, and saved; the day of extravagant waste, in the mine, on the bank, and at the coke oven, must speedily come to an end, and the small coal left in the mine hitherto must be brought to the surface and utilised, and a careful stripping made of all the coal adhering to stone, and usually placed on the tip bank and wasted. The coal when mixed up with rock can be crushed between rollers, and put through a washing machine, and a large proportion of it can thus be recovered; some of it is really first-class coking coal. The modern appliances for performing these operations are now so perfect, and are run at so little expense, that it is quite reasonable to expect some enterprising people thus to work up their dumps, especially as coal becomes dearer and scarcer.

The demand for hard foundry coke has to some extent at least kept the Beehive process alive, and Beehive foundry coke always carries a higher price in the market than by-product furnace coke, and buyers are not so stupid

as to pay a higher price for an article that is not better than a lower-priced one ; but there is a marked difference in the two articles, Beehive coke and by-product horizontal-oven coke ; the former is produced by a process altogether different from the latter, and is by this process necessarily exposed to a longer period of carbonisation, and since the process is conducted from the top downwards, the progress of the heating and coking is slow. The tar and heavy hydrocarbons contained in the gas have to make their exit either through or past the pasty molten layer of coal next to and beneath the incandescent coke ; the gas and tar are there divested of their fixed carbon, which is filtered from them, retained in the coal, and finally coked. There is not the slightest doubt that as a process of producing the best coke, it cannot be beaten. The improvements shown in the various patents cited above do not tend, nor perhaps was it thus the intention of the inventor, towards an improvement in quality, so much as a cheapening and expedition of the process.

The heating of a Beehive oven, otherwise than by the original means, at the top, would tend to shorten the time of carbonisation ; but time is a factor in producing high quality coke. When coal after it has been coked is kept at a high temperature for 24 to 36 hours it is gradually changed in character ; it is consistent with reason to suppose that coke cannot be kept at this temperature in an unchangeable state ; it loses weight, gas is evolved, the carbon is thereby consolidated and hardened, soft sponginess is eliminated, any tarry matters not quite coked in the interstices of the cells are thoroughly carbonised ; this can only be gained by prolonged heating ; like the baking of a piece of clay, the longer it is fired the denser and more consolidated it becomes.

Now comes the question, is such hard, consolidated coke necessary ? The fact of its being sold at a higher price, to the exclusion of other coke, should be an answer ; but the real reason is that this *foundry coke* is used for foundry purposes, and must be hard, pure, free as possible from ash, sulphur, and any other deleterious matter, and be able to stand the weight of the heavy pigs of iron thrown into the cupola upon it, without being crushed ; and finally, present to the molten iron, as it trickles down upon it, a surface that is non-absorbtive, that is, will not absorb the molten liquid iron as a piece of soft coke will do. The consequence is, that when any other coke is used, that has not had the same hardening treatment, the molten iron is absorbed into the coke in the region above the tuyeres, so that when this piece of coke has arrived before the tuyere, and the blast oxidises it to CO_2, the blast also oxidises the iron very rapidly, held before it by the coke in a fine state of sub-division.

The ideal method of melting iron in the foundry is to melt it and get it into the sump as quickly as possible, and without loss, and this is only possible by using coke of a hard, dense nature, and it is for this reason, more than for any other, that Beehive foundry coke is preferred to by-product coke.

Expediting the coking process in Beehive ovens by any means, is simply depreciating the standard of quality down to that made by the by-product horizontal ovens. These latter ovens coke coal in 18 to 36 hours, according to type and the method used for heating the oven.

The reduction of the time of coking in the Beehive or any other oven below 36 hours has a deleterious effect upon the coke produced, as regards quality and hardness ; and it may be that the want of success of some of the hundreds of inventions patented for improvements in Beehive ovens has been due to this cause.

With regard to the last cited patented invention for the carbonisation of coal in Beehive ovens, by Messrs. Otto, this doubtless came on the market too

late, as the horizontal oven had been designed to make the class of furnace coke required, at a high temperature, in narrow ovens, and cheaper than could be possible in a Beehive oven; but the propositions put forward by this last invention brought the Beehive oven on a line with its rival—the horizontal by-product oven—a rival with whom it could not possibly compete, because the one was designed to make a class of coke quite different from the other, but by adapting details suited to the horizontal by-product oven, and applying them to the old type Beehive oven, would certainly give a greater output than the old Beehive oven, and probably better coke than the new horizontal oven, since it would be a longer time in coking; but it would not be so economical to work, the labour charges would be greater, and the time occupied longer than in the latter oven; the coke produced would be inferior to that made by the old process, and the improvement effected on the quality, compared with the horizontal oven, would be so trifling that it could not prove a commercial success.

The principle shown in this last invention, however, is the correct one, *i.e.*, heating a furnace with gas, that is, if gas is used as a fuel for heating purposes; it should be burned with heated air—whether the air is heated by means of a regenerator or a recuperator is immaterial; the effect of heating the air for the combustion of the gas ensures as complete combustion as possible, whereas, when gas is burned without heated air, it is not wholly consumed, and perfect combustion is difficult, especially with gas containing large amounts of diluents; and if the air is very cold, as it would be in winter, a certain amount of heat has to be spent in raising its temperature, or inversely by mixing cold air with the gas, which probably is also cold, and raising up to the point of ignition, whereas when the air, or gas, or both are pre-heated, ignition is hastened; and if the pre-heating is accomplished by waste heat, otherwise lost, a great economy is ensured, by carrying back to the furnace the heat units in the form of heated air or gas. Upon this principle Siemens constructed his first regenerative gas furnace, by which higher temperatures and cleaner work was accomplished than had hitherto been possible.

However, the principle applied to Beehive coke ovens was completely out of place, and to a certain extent the Otto Company have discarded this principle, even in their horizontal by-product ovens, in favour of their atmospheric burner method, which is fully described in the chapter dealing with the development of the horizontal by-product oven.

There are other reasons why regenerative firing may be superseded as stated above. The very high temperature that can be developed in the flues may be ruinous, and unless great care and attention is observed, and the highest quality of firebrick used, the flues are soon destroyed, especially when using rich gas. The high cost of construction of regenerators, and the amount of space occupied, are all factors that are to be considered, and, as stated above, are superfluous for Beehive oven practice, the temperature developed by the old method being quite sufficient to coke the coal slowly, so that the requisite amount of time may be expended on the carbonisation to form the first quality coke. The question of the economical working for the production of Beehive foundry coke and by-product furnace coke, cannot be compared for the two cases; the former is a most wasteful and extravagant process, while the latter has been proved to be most economical and remunerative. Whether the quality of the foundry coke produced in Beehive ovens can be produced by any process using the same time in carbonising and with other conditions similar, and producing an article of same quality and appearance in all other respects, will be dealt

with in another part of this work, when describing by-product vertical coke ovens.

Notwithstanding all the improvements referred to above in the several patents cited, together with the numerous other patents taken out in connection with Beehive ovens, the bulk of the foundry coke is to-day made by the original method, by means of an oven either round or oval in plan and approximating to 10 feet in diameter and 5 feet in height, and which can be seen working at present in Durham, Northumberland, and elsewhere. Dr. Percy gives a description by Parkes of one of these old ovens which were in use at the Duke of Norfolk's Colliery, near Sheffield, at the beginning of last century.

It is stated that these ovens were circular in plan, 10 feet in diameter, built of brick with a floor of the same material set edgeways. The walls of the oven were 18 inches thick, and rose vertically 19 inches above the floor, and were surmounted by a conical roof, of which the apex within was 22 inches above the floor. Good square bricks were used, well built, so that the joints were very thin, to prevent the ingress of air. The total height of the oven outside was 5 feet.

The floor was raised 3 feet from the ground, in order that a wheelbarrow or low waggon might be placed under the doorway to receive the coke when drawn from the oven.

The oven was enclosed on the outside by four walls of stone, about 20 inches thick; the corners, between the outer circular wall and the stone wall, were filled in solid with rubbish, well rammed, in order to strengthen the work, retain the heat, and exclude the air.

Although this oven differs from those in use at present in the height of the roof inside, and in other details, the mode of conducting the process was the same as is now practised, viz., small coal slack was charged through the hole in the crown of the arch to fill the oven up to the springing line of the roof, and then levelled with an iron rake, after which the doorway was built up with dry bricks, and then luted over with loam.

The heat retained in the walls and floor of the oven from a previous charge generally was sufficient to fire the charge, and the combustion was kept up by the air finding its way through the joints in the brickwork in the doors, which were kept open during the first stage of the process. After the coal was well ignited, it was necessary to check the combustion to a certain extent, and this was accomplished by plastering over the doorway with wet loam, except the top row of bricks, which were left all night unplastered. Next morning, the charge having been in the oven 24 hours, the joints in the top row of bricks were completely closed, but the chimney draught was left open until the flame from the hole in the roof disappeared, which generally occurred after a further 12 hours. The charging hole in the roof, which also served as a chimney, was now completely covered up with stones and earth, so as to exclude the air, and the oven was left for another 12 hours to complete the operation of carbonisation.

After cooling the coke, by throwing in water, the doorway of loose bricks was taken down, and the coke raked out into wheelbarrows. This oven was usually charged with 2 tons of coal, and the operation of carbonisation, lasting 48 hours, is stated to have produced coke, ponderous, extremely hard, light grey, bright, and metallic in lustre.

The ovens now in operation for the manufacture of Beehive foundry coke are generally constructed in rows, back to back, with a waste heat flue between

each row of ovens, leading to steam boilers, and through them to the chimney stack. The ovens are made higher in the roof, and take larger charges of coal; the period of carbonisation lasts from 48 to 72 hours.

Composition of Gases Evolved from Beehive Ovens.—Ebelman conducted a series of experiments at Seraing in Belgium, and quoted by Dr. Percy from *Recueil des Travaux Scientifiques*, II., 142. He gives details of the oven and the analyses of the gases he examined, as follows :—

"The floor of the oven is a rectangle; the roof is cylindrical above the rectangle, and conical above the trapeziums. There are three chimneys in a line, one in the centre of the cylindrical part of the roof, and one on each side of the junction of the cylindrical with the conical part of the roof. The area of the central chimney is double that of each of the others; the three are never in use at the same time; the two lateral chimneys are closed when the central one is open, and conversely. The central chimney conducts the gases which escape from the oven, under the boiler of a steam engine. Caking coal was coked in these ovens, which yielded 80 per cent. of coke, consisting of 78 parts of carbon, 2 per cent. of ashes, and 20 per cent. of volatile matters. Ebelman gives no elementary analysis of this coal, but inferred its composition from that of a coal at Rochebelle, near Alais, which yielded very nearly the same percentage of coke, namely, 78 per cent., and of which the following analysis was made by Regnault :—

Composition, per cent., of Coal from Rochebelle used for Coking.

Carbon,	89·27
Hydrogen,	4·85
Oxygen and nitrogen,	4·47
Ash,	1·41
	100·00

"The charge for each oven is 3 cubic metres (= 2,750 kilograms or 2 tons 14 cwts. 16 lbs.) of small coal, which is spread as evenly as possible over the floor, forming a stratum about 0·33 metre (= 12·99 inches in thickness). All the chimneys are open at this time for the comfort of the workmen. When the charging is over, the lateral chimneys remain open while the central one is closed, and continue so for two or three hours; the doorways are closed, but not luted, and carbonisation commences. It may be divided into three stages, as follows: —In the first stage, which lasts about three-quarters of an hour, there is only disengagement of water; in the second stage, which lasts about an hour and a half, the gases take fire and partially burn with a very smoky, red flame, the lateral chimneys remain wide open, and the doorways are closed, but not luted; in the third stage, the gases burn well with a smokeless, white flame. The coal appears incandescent to the depth of 8 or 10 centimetres (3 to 4 inches) from the surface; the doors are then luted, and only a small fissure is made in the clay luting at the upper part. The lateral chimneys may now be closed, and the central one entirely opened. When the flame begins to decrease, the fissure in the clay luting is gradually contracted, and at last completely stopped, and when flame ceases the central chimney is closed. The period of coking, inclusive of charging and drawing, lasts from 22 to 24 hours. The average yield of coke is 160 per cent. in volume, and 67 per cent.

in weight.* Ebelman analysed the gases collected from these ovens at three different stages of the process, and obtained the following volumetric results :—

TABLE SHOWING THE COMPOSITION PER CENT. BY VOLUME OF THE GASES EVOLVED FROM COKE OVENS AT SERAING DURING COKING.

	I.	II.	III.	IV.
Carbonic acid . . .	10·13	9·60	13·06	10·93
Carbonic oxide, . . .	4·17	3·91	2·19	3·42
Marsh gas, ...	1·44	1·66	0·40	1·17
Hydrogen, ...	6·28	3·67	1·10	3·68
Nitrogen, ...	77·98	81·16	83·25	80·80
	100·00	100·00	100·00	100·00
Number of volumes of oxygen combined with carbon in relation to 100 volumes of nitrogen, . . .	15·7	14·2	17·0	15·63

I. = Gas collected, two hours after the kindling of a charge, from one of the lateral chimneys of an oven; smoke black and dense; reddish flame appearing at intervals. II. = Gas collected 7½ hours after charging; bright, but still somewhat reddish flame, without smoke. III. = Gas collected after 14 hours coking; flame clear, but little in volume; carbonisation being apparently near completion. IV. The mean of I., II., and III.

" The relation in weight between the elements contained in the mean of the gases (IV. in the preceding table) is as follows :—†

Carbon, . .	In carbonic acid, ...	1·408	2·004
	In carbonic oxide, ...	0·443	
	In marsh gas, ...	0·153	
Oxygen, . .	In carbonic acid, ...	3·758	4·348
	In carbonic oxide, ...	0·590	
Hydrogen, .	In a free state, ...	0·079	0·130
	In marsh gas, ...	0·051	
Nitrogen, ...		24·353	
		30·835	
Oxygen which has disappeared as deduced from the ratio existing between nitrogen and oxygen in atmospheric air,		2·925 ‡	

" The percentage of coke obtained was 67, so that 33 per cent. of the coal had been removed either by volatilisation or combustion. Now, assuming

* It has been stated above that the coal used yielded 80 per cent. of coke, but this is scarcely possible in a Beehive oven; the 67 per cent. is the most probable percentage.

† Data from which these calculations have been made at 760 mm. (= 30 in.) pressure, and 15·5° C. (60° F.) :—

	Grains.
100 cubic inches of carbonic acid weigh . . .	47·26
„ „ carbonic oxide weigh . . .	30·21
„ „ oxygen weigh	34·29
„ „ hydrogen weigh	2·14
„ „ marsh gas weigh	17·41
„ „ nitrogen weigh	30·14

‡ 24·353 parts of nitrogen are associated with 7·273 parts of oxygen in atmospheric air; hence 7·273 — 4·348 = 2·925.

that the composition of the coal used was identical with that of the Rochebelle coal previously given, and supposing that the 67 per cent. of coke consisted of 65·59 parts of carbon and 1·41 of ashes, it follows that the 33 per cent. of matter removed during coking contained the following elements :—

Carbon, ...	23·68 per cent.
Hydrogen, ...	4·85 ,,
Oxygen and nitrogen, ...	4·47 ,,
	33·00 ,,

" Thus, the relation in weight between the carbon and hydrogen is as 1 : 0·205 ; but the relation in weight between the carbon and hydrogen deduced from the mean composition of the gases above stated is as 1 : 0·065.

" Hence, Ebelman draws the conclusion that more than two-thirds of the hydrogen contained in the coal are burned during the process of coking, and being converted into water, this part of the hydrogen does not appear in his analysis. He remarks, however, that in this computation no account is taken of the amount of tar and other condensable matters evolved during the process ; but he considers that in consequence of the very high temperature of the oven during nearly the whole period of coking, the proportion of condensable products is of little account, and that it is only at the beginning of the operation that they are disengaged in appreciable quantity. It must be borne in mind that the data from which Ebelman draws his conclusions involve an assumption as to the composition of the coal of which no analysis was made.

" The volume of oxygen combined with carbon in the mean of the gases (IV. in the table) is to that of the nitrogen as 15·63 : 100 ; whereas the relation in volume between the oxygen and nitrogen which entered the oven in the state of atmospheric air is as 26·26 : 100. The difference, 10·63, represents the volume of oxygen which has served to burn the hydrogen. Hence two-fifths (by weight as well as by volume) of the oxygen of the air introduced into the coke-oven have been converted into water. In this calculation Ebelman remarks that the small amount of oxygen contained in the coal has been neglected, but that the correction required to be made in consequence will not sensibly affect the conclusions enunciated.

" The quantity of atmospheric air which the process of coking will require may also be deduced from the composition of the gases. The relation in weight between the nitrogen and carbon in the mean of the gases is as 12·2 : 1. Atmospheric air contains 77 per cent. of nitrogen by weight ; consequently, for 1 part by weight of carbon in the gases, 15·8 of air will enter the oven. Now, it has previously been stated that the quantity of carbon carried off in the gases is 23·68 per cent. of the weight of the coal ; the weight of air therefore introduced during the process of coking is to that of coal as 3·74 : 1.

" Hence, in coking 2 tons 14 cwts. 16 lbs. (= 2,750 kilograms) of coal not less than 10 tons 2 cwts. 55 lbs. of air will be required, or in volume 296,188 cubic feet (100 cubic inches of air weigh 31·0117 grains, or 1 lb. of air = 13·06 cubic feet). Supposing the duration of the coking process to be 24 hours, 12,341 cubic feet of air will enter the oven per hour, very nearly 205·7 cubic feet per minute, and 3·43 cubic feet per second. Ebelman estimated that this amounted to about two-thirds of the air blown into a charcoal iron-smelting furnace yielding 2 tons of pig-iron in 24 hours.

" From the data which Ebelman obtained in his investigations concerning

the composition of the gases of the coke-ovens at Seraing may be approximately calculated the amount of heat produced during the process of coking, as well as the amount which may be further developed by the complete combustion of the carbonic oxide, hydrogen, and marsh gas existing in those gases. Ebelman made such a calculation, and came to the conclusion that two-thirds of the heat capable of being evolved by the complete oxidation of the volatile products were rendered sensible in the ovens, and only one-third remained to be generated by the subsequent oxidation of the combustible constituents of the gases which escaped from the ovens.

" Suppose that the coal employed yielded 67 per cent. of coke, and 33 per cent. of volatile products, consisting of 4·85 of hydrogen, 23·68 of carbon, 2·97 of oxygen, and 1·50 of nitrogen ; and granted that only the amount of hydrogen in excess of what is required to form water with the oxygen in the coal is available as a source of heat, namely, 4·479 ; then, for 1 part by weight of coal, 0·04479 of hydrogen, and 0·2368 of carbon will be evolved and partially burnt during the process of coking ; and the number of units of heat which will be produced by the conversion of the hydrogen into water and the carbon into carbonic acid will be respectively $0·04479 \times 34,000$[1] $= 1,522·860$, and $0·2368 \times 8,080$[5] $= 1,913·344$. But as the water formed from the hydrogen will pass off as steam at the temperature of at least 100° C., it is necessary to deduct the latent heat of the steam ; for it will be remembered that in the determination of the calorific power of hydrogen in the calorimeter, the vapour of the water produced is condensed, and its latent heat rendered sensible. Not only must the latent heat of the steam resulting from the combustion of the disposable hydrogen be deducted, but also that of the non-disposable hydrogen, which is supposed to exist as water in the coal. Hence the total amount of latent heat to be deducted is $0·0485 \times 9 \times 537 = 234·400$. The real number of available units of heat from the hydrogen will, consequently, be $1,522·860 - 234·400 = 1,288·460$; and the sum of the units of heat capable of being produced from the carbon and hydrogen, which are evolved from 1 part by weight of coal, but only partially burnt during the process of coking, will be $1,913·344 + 1,288·460 = 3,201·804$.

" The number of units of heat resulting from the combustion effected within the oven during the coking process is easily found.

" The total quantity of carbon in the gases produced from 1 part by weight of coal is 0·2368, since 100 parts of coal yielded 33 per cent. of such products, of which 23·68 consisted of carbon. Now, in the mean of the gases of the coke-ovens at Seraing (IV. in the table, page 207), which contained 2·004 parts of carbon by weight, 1·408 were present in carbonic acid, 0·443 in carbonic oxide, and 0·153 in marsh gas ; hence of the total weight of carbon, 0·2368, in the gases produced during the coking of 1 part by weight of coal, 0·1664 existed in carbonic acid, 0·0523 in carbonic oxide, and 0·0181 in marsh gas.

" The number of units of heat, therefore, resulting from the combustion of carbon in the oven is $(0·1664 \times 8,080) + (0·0523 \times 2·473$[6]$) = 1,473·850$. The weight of hydrogen burnt in the oven is $0·04479 - 0·01536 = 0·02943$ per unit weight of coal ; and the number of units of heat which will result from its combustion, making the deduction required for the latent heat of the steam thereby produced, as well as the steam which is represented by the non-disposable hydrogen in the coal is $(0·02943 \times 34,000) - [(0·02943 + 0·00371) \times 9 \times 537] = 840·455$. The total number of units of heat resulting from the combustion of carbon and hydrogen in the oven is, therefore, $1,473·850 + 840·455 = 2,314·305$.

"The number of units of heat which will be evolved by the perfect combustion of the carbonic oxide, hydrogen, and marsh gas in the gases escaping from the oven may also be found in a similar manner. The carbon and hydrogen in marsh gas may be regarded as in a free state, since the calorific power of this gas is nearly the mean of the calorific powers of its constituents. Hence, in the gases produced during the coking of 1 part by weight of coal, 0·04479 — 0·02943 = 0·01536 of hydrogen will be present in a practically free state, and the number of units of heat which will result from the combination of this hydrogen, making the deduction required for the latent heat of the steam produced, is (0·01536 × 34,000) — (0·01536 × 9 × 537) = 448·005.

"The number of units of heat which will be developed by the combustion of the carbon in carbonic oxide is 0·0523 × 5,607[7] = 293·246; and by the combustion of the carbon in marsh gas, 0·0181 × 8,080 = 146·248. Therefore, the total number of units of heat remaining to be produced by the complete combustion of the gases which escape from the oven is 448·005 + 293·246 + 146·248 = 887·499.

"From the preceding data it appears that the total maximum number of units of heat capable of being evolved by the perfect combustion of the carbon and hydrogen, separated from 1 part by weight of coal during the process of coking, is 3,201·804, of which number 2,314·305 units are produced during the process of coking, and 887·499 remain to be produced from the gases evolved.

"Hence the ratio between the number of units of heat produced and of those which remain to be produced, somewhat exceeds 2 : 1; and it follows that the maximum number of units of heat capable of being developed during the coking of 2,750 kilograms of this coal is 8,804,961,000, of which 2,440,622,000 remain to be produced by the combustion of the gases escaping from the oven. A tabular statement of the foregoing calculations is given on opposite page.

"The preceding approximate calculations must be correct if the data upon which they are founded be true; but let us now inquire whether we have reason to doubt the truth of these data. In the mean of the gases, 24·353 parts by weight of nitrogen were associated with 4·348 of oxygen, which existed in combination with carbon. In atmospheric air the same weight of nitrogen is associated with 7·273 of oxygen; and as the nitrogen present in the gases was *practically* all derived from atmospheric air, it follows that 7·273 — 4·348 = 2·925 parts by weight of oxygen have disappeared in consequence of its combining with hydrogen during the process of coking. But the relation in weight between the oxygen which has disappeared and the carbon in the mean of the gases is 2·925 : 2·004. Hence the weight of the oxygen which has disappeared in the coking of 1 part by weight of coal is 0·2368 × (2·925 ÷ 2·004) = 0·3456; but 0·3456 of oxygen would require 0·0432 of hydrogen to combine with it during the process of coking; and if we add to this 0·01536, the weight of hydrogen evolved partly free and partly in combination with carbon as marsh gas, we obtain 0·05856 as the total weight of disposable hydrogen per unit weight of coal, which is 0·05856 — 0·04479 = 0·01377 in excess of the true weight. It may, therefore, be inferred that the data of Ebelman cannot all be correct. The composition of the coal, and the weight and elementary composition of the samples of gases produced during the process of coking, may be exactly determined; but it must, obviously, be very difficult to arrive at the correct average composition of the gases and volatile products evolved during the process of coking.

"The three specimens of gas which Ebelman collected at intervals of 2 hours,

TABULAR STATEMENT OF THE PRECEDING CALCULATIONS OF THE AMOUNT OF SENSIBLE HEAT PRODUCED, AND OF COMBUSTIBLE GASES EVOLVED, DURING THE PROCESS OF COKING IN OVENS AT SERAING.

Weight of each Element evolved during Coking, per Unit Weight of Coal.	Supporter of Combustion.	Product of Combustion.	Units of Heat Evolved.	Latent Heat to be Deducted.	Available Units of Heat.		
C, 0·2368, . . .	O_2 of air, .	Carbonic acid, .	1,913·344	..	1,913·344	= Units of heat available by the perfect combustion of the carbon and hydrogen evolved from 1 part by weight of coal during coking,	= 3,201·804
H, 0·0485 = 0·04479, .	O_2 of air, .	Water, . .	1,522·860	234·400	1,288·460		
H, 0·0485 = 0·00371, .	Virtually exist in the	combination in coal,	Nil				
O, 0·0297, . .							
N, 0·0150, . . .	Nil, . .	Nil, . .	..	..	..		
Weight of Carbon and Hydrogen Burned in Oven.	**Supporter of Combustion.**	**Product of Combustion.**	**Units of Heat Evolved.**	**Latent Heat to be Deducted.**	**Available Units of Heat.**		
C, 0·2187 = 0·1664, .	O_2 of air, .	Carbonic acid, .	1,344·512	..	1,344·512	= Units of heat given out by the combustion of carbon and hydrogen in the oven, . .	= 2,314·305
C, 0·2187 = 0·0523, .	O_2 of air, .	Carbonic oxide,	129·338	..	129·338		
H, 0·02943, . . .	O_2 of air, .	Water, . .	1,000·620	160·165*	840·455		
Weight of Carbon and Hydrogen to be Burned after leaving the Oven.	**On leaving the Oven Exists as**	**Product of Combustion in Air.**	**Units of Heat Evolved.**	**Latent Heat to be Deducted.**	**Available Units of Heat.**		
C, 0·074 = 0·0523, .	Carbonic oxide,	Carbonic acid, .	293·246	..	293·246	= Units of heat obtainable by the perfect combination of the carbonic oxide, marsh-gas, and free hydrogen which escape from the oven,	= 887·499
C, 0·074 = 0·0181	Marsh gas, .	Do., . .	146·248	..	146·248		
H, 0·01536 = 0·00603		Water, .					
H, 0·01536 = 0·00933 .	Free, . .	Do., .	522·240	74·235	448·005		
Total, as above, ...							3,201·804

* Includes the latent heat of the hydrogen and oxygen, assumed to exist in combination as water, in coal.

7½ hours, and 14 hours after the commencement of the process are assuredly quite insufficient for the purpose.

"Thick yellow smoke is copiously evolved at an early stage of the process; but the matter which produces this smoke, and which cannot be inconsiderable in amount, is not represented in the mean composition of the gases collected. It seems, therefore, most probable that the opposite conclusions concerning the amount of hydrogen consumed during the process of coking are due to an error in the average composition of the gases.

"Nevertheless, it is certain that not only is a large amount of heat developed in the process of coking, but also that a considerable additional amount may be obtained by the combustion of the carbonic oxide, hydrogen, and marsh gas existing in the gases which escape from the ovens; but whether these combustible gases, which are mixed with so large a proportion of carbonic acid and nitrogen, can be *perfectly* burned by atmospheric air seems to be more than doubtful.

"Ebelman draws the practical and obvious conclusion that, as a very large proportion of the heat available from coke ovens is *sensible* heat, it is desirable that the distance between the ovens and the place of the application of the waste gases escaping from them should be as short as possible."

The foregoing details of the experiments of Ebelman as criticised by Dr. Percy are instructive, showing conclusively the waste of heat and valuable by-products in the process of the Beehive carbonisation of coal.

The great difficulty in dealing economically with half-burned gases such as those mentioned and alluded to by Dr. Percy above, is their combustion; if it were possible to keep them at a high temperature, and mix them with highly heated air, combustion might be made possible; but as it is more probable that their temperature is low comparatively, and their dilution high, with carbonic acid and nitrogen, further combustion is practically impossible with cold air; the waste heat in the gases is, therefore, used for raising steam, by passing the gases through boilers without further combustion, but, as stated above by Ebelman, the boilers must be quite close to the ovens, otherwise the sensible heat will be lost before reaching the boilers.

This process of carbonising coal is still maintained in parts of Durham and Northumberland, using the waste heat for raising steam, in the manner stated above, mostly in districts where the coal cannot be coked in by-product ovens.

CHAPTER VIII.

CARBONISATION OF COAL IN HORIZONTAL BY-PRODUCT OVENS.

The history of the horizontal oven is very short, and only goes back to quite a recent date, and, as far as can be ascertained, it was Joze Luis, of London, who seems to have been the first to have applied for a patent for this class of oven (British patent 2082 of 1858). The following is an extract from his patent :—

" These kilns are for the conversion of small coal into coke for the extraction of gas, coal tar, and ammoniacal waters.

" The kilns which are preferable for smith's coal are of a horizontal form, being 1 yard in width and 6 yards in length, and the height of the pit coal in the oven about 20 inches.

" For the coal between smith's coal and glance coal a kiln of the same length is used, but the width in this case is only 27 inches instead of 1 yard.

" And, lastly, for the glance or close burning coal and stone coal, or for a mixture of glance coal and smith's coal, or stone coal, vertical kilns must be used of a quadrangular or rectangular form, holding a quantity of coal, which sinks of its own weight, or is pressed down and is heated by tubes surrounding the entire circumference.

" The operation of carbonisation is as follows :—In all these cases the kilns are furnished with the same apparatus for conducting the volatile products, of which the greater part becomes condensed, and is thus collected.

" The following explanation is applicable to each of the above-mentioned kilns, the letters in the drawings in figs. 82 and 83 referring to the same objects in each figure.

" As soon as the introduction of the coal has taken place, care must be taken to lute the doors, A, of the furnace.

" During the first part of the operation, and while the coal is becoming a paste, the volatile products which escape are only vapour from water ; these vapours escape by the only issues, *b*, left open, and then enter the chimney, after having passed through the different tubes which surround the furnace. To cause this first operation of carbonisation to proceed quicker, hot air is introduced into the interior of the furnace by the openings, *c*, for that purpose ; this operation lasts generally one hour. The communications are then shut by means of a cap *f*, as well as the introductions for hot air *c*, and the volatile products which escape from the coal in fusion enter into the pump chamber, *y*, fig. 83, raising the obturator or closing apparatus *h*, the edges of which rest in coal tar collected in the vessels *y*, the coal tar furnishing a perfect lute. These volatile products are drawn up by the machine, which operates in such a manner as to preserve always an equilibrium in pressure at *o ;* the volatile products traverse the pump chamber, leaving in condensation a large part of the coal tar, and of the ammoniacal waters ; they pass through the condenser, where they debarass themselves of the rest of the coal tar, and enter into one of the

bell receivers of the machine, and are gathered in a gasometer, but passing, of course, through purifiers when intended for gas for burning. A pipe, *m*, leading from the gasometer brings a sufficient quantity to each oven or kiln; the quantity is regulated by the obturator according to the requirements of heating. The gas circulates in the tubes, *d*, fig. 83, surrounding the coal to be carbonised, and receives by the openings, *o*, the hot air necessary to the combustion. This operation continues generally eighteen hours, as long as the coal contains hydrocarburet; then the same proceeding which was performed at the commencement of the operation is repeated, the obturator, *h*, is lowered, the communicators, *b*, opened, and the introduction of hot air established. The operation terminates by producing in the interior of the retort containing the coal a very high temperature, which destroys the bituminous particles which are condensed on the vault of the furnace, and on the upper part of the coal. By a sight plate arranged in one of the doors of the furnace the workman can from time to time see how the carbonisation is going on, and when he perceives that nothing is given off except a few small blue flames he can empty the furnace with a machine, *x*, for that purpose. The blue flame is the hydrogen

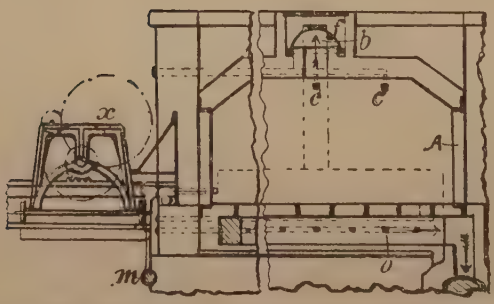


Fig. 82.—Longitudinal Section of "Luis" Horizontal Coke Oven.

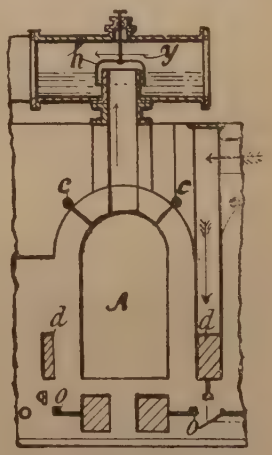


Fig. 83.—Cross-Section of "Luis" Oven.

burning. The liquid contained in the pump chambers and in the condenser is drawn off into receptacles, whence it is withdrawn to be rectified. From the ammoniacal waters sulphates of ammonia are made, and from the coal tar light oils are made for burning, and heavy oils for painting and the preservation of wood."

This important communication at this early date contains the whole of the essentials, and a number of the details and principles underlying the modern coke-oven practice. The process is evidently the first step from the Beehive coke oven to the modern horizontal by-product oven.

It will be seen that the idea of complete carbonisation by means of external heat had not yet been fully developed, because Luis only heats by means of external flues the lower part of the oven, and the upper part is not heated at all; but provision is made for the complete carbonisation of the whole charge, as will be gathered from the specification, where he states, "This operation continues generally eighteen hours, as long as the coal contains hydrocarburet;

then the same procedure which was carried out at the commencement of the operation is repeated, the obturator, *h*, is lowered, the communicators, *b*, opened, and the introduction of hot air established. The operation terminates by causing, in the interior of the retort containing the coal, a very high temperature, which destroys the bituminous particles which are condensed on the vault of the furnace and on the upper part of the coal." Luis, therefore, evidently commences to finish the coking of the upper part of the charge by allowing hot air to enter the oven after closing the gas valves, and thus set fire to the tar and the upper part of the coal which is not yet carbonised. In order to prepare the oven for the next charge, he thus secures a very high temperature in the interior. Apart from this defect in the process, it is practically the same in almost every detail as the modern horizontal oven process. The gases are extracted during the carbonisation by means of an exhauster, which the inventor terms "a pump." The bottom of the oven, as well as the sides, is heated by flues, and if the horizontal heating flues had been continued higher up, the top part of the oven would have been heated, and the final stage as described above done away with; but perhaps there was a reason for not permitting the walls to be heated all the way up as in the more modern ovens; perhaps the inventor anticipated the modern defect of destroying the gases by reason of the hot region at the top of the ovens, where the hydrocarbon gases are split up into permanent gases, and certain valuable by-products thus sacrificed; if these facts were anticipated in this invention, an enormous step is shown in the direction of obtaining coke and all the by-products. The inventor not only makes a sudden leap from the wasteful process of the Bee-hive oven practice as regards carbonisation, but also anticipates in a very accurate manner the discharging of the horizontal oven by means of a ram when the charge is completely carbonised. There is also the regenerative principle here adopted upon the sound basis of employing pre-heated air for the combustion of the gas that is first extracted by "the pumps," and is again brought back to the oven to heat the flues, in the same manner as at present.

It will be observed that the inventor divides his process into three distinct treatments of the coal, and uses his oven in three forms, which are not shown in the drawings. The oven illustrated by the figs. 82 and 83 are, according to the specification, for the purpose of carbonising "smith's coal," and are stated to be 6 yards long and 1 yard wide; the height of the "pit coal" in the chamber is about 20 inches; the height of the chamber is not given, but, judging from the other dimensions, viz., the width, it must be about 6 feet in height. No reason is given why a chamber 6 feet in height is required to carbonise coal only 20 inches in depth; such a chamber only being heated by one flue in the side walls, towards the bottom, it is evident that the upper part of the chamber was designed to be cool, but why such a height? Luis states that for other classes of coal such a tall chamber is necessary, and must also be heated by flues to the total height, but no drawing of this chamber is given, and it is, therefore, reasonable to suppose that in such a chamber "heated by tubes surrounding the entire circumference," the proposal to stop the gas exits and to set fire to the coal and tar in the oven would not be required; since the width of the chamber would be only 27 inches, the oven would be practically the same as one of the modern ovens in construction and dimensions. It may be supposed, on the other hand, that the inventor had in his mind, when stating the depth of the "smith's coal" or "pit coal" to be only 20 inches, that he was intending to carbonise the high-fat coal that cokes only with much swelling up, and which at present cannot be coked in the modern horizontal by-product

coke oven, by reason of this excessive swelling up, which blocks up the exit gas pipes and causes very serious hindrance to the progress of the carbonisation. In this case the inventor was quite correct, and his comparatively low temperature carbonisation by means of the gas-heated flues in the floor and the walls of the coking chamber would answer the purpose admirably, followed by the process of finishing the charge by the high temperature provided by the burning of the tar and the upper layer of coal in the chamber.

It is also evident from what follows in his statement in the specification ("For the coal between smith's coal and glance coal, a kiln of the same length is used, but the width in this case is only 27 inches, instead of 1 yard") that he was dealing with a coal that did not swell up so much; but the great width of the other oven as compared with the more modern type would lead one to suppose that he was intending to make the best foundry coke, and to carry on the process for 48 to 60 hours. It is obvious, however, that if an oven 6 feet high and 27 inches wide was practically filled with coal, and if the flues in the walls were only as shown in the drawing, it would be extremely difficult to coke the charge as described in the specification, even if, after "eighteen hours coking" by means of the heating tubes in the walls, he resorted to the method of carbonising by burning the coal and tar inside the chamber; owing to the narrowness of the latter, the loss of coke before the charge was fully carbonised would render the process prohibitive.

With regard to his last suggestion, for coking "the glance or close-burning coal, and stone coal, or a mixture of glance coal and smith's coal or stone coal, vertical kilns must be used of a quadrangular or rectangular form, holding a quantity of coal which sinks of its own weight, or is pressed down and is heated by tubes surrounding the entire circumference." These vertical kilns are not shown in the drawings, nor is any further description of them given; probably the inventor was here referring to the vertical ovens for coking coal invented by Appolt Brothers, details of which were published in the same year, 1858; a description of these ovens is given in Chapter IX.

Coking coal in the absence of air, in horizontal ovens externally fired, had for its object the saving of the valuable by-products, tar, gas, ammonia, and benzol. This could not be accomplished by the old method in the heap or stall, or in the Beehive oven, with any degree of success, and we find other inventors busy with propositions to accomplish these ends; Pernolet in 1862 (British Patent 1774) proposes to coke the coal and save the by-products in a similar manner to that just described; he first passes the gas to the condensers, takes out the by-products, and returns the gas to the flues to heat the ovens; but in this oven he burns the gas in a fireplace under the oven, the products of combustion passing away by means of flues surrounding the oven. The procedure is as follows:—

Charges are supplied from trucks through openings, D, fig. 84, to the oven A, and the coal is spread evenly on the bed, *s*, by rakes introduced through the sides, where the doors, *d*, are lowered by windlasses G. The volatile products issue through passages, F, into condensing chambers formed by close thin metal plates kept cool by water which falls from the reservoir into the chambers. The tar and other liquefied products fall into troughs. From these condensers the gases may be forced up through a downward water spray from the reservoir and deprived of the ammoniacal products. They then pass through pipes to the fireplace, *f*, fig. 84, of the oven, into which jets of air are forced, the combustion taking place round the heating flues of the oven. The coke is removed from the oven on to the inclined plane by a discharger which is pushed through

the oven by an engine, upon traversing rails laid along the front of the line of ovens.

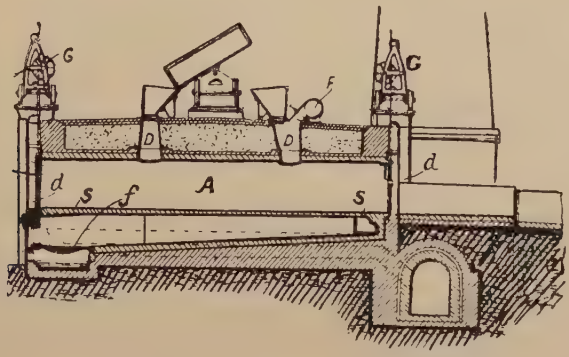


Fig. 84.—Longitudinal Section of " Pernolet " Horizontal Oven.

The Coppée Coke Ovens.—There was no other oven designed on the horizontal principle until the year 1868, when Evance Coppée obtained a patent for his invention (B.P. 2152), but he does not save the by-products, burning the gas in the flues surrounding the oven ; he proposes to use the gas produced in one oven to heat the adjoining ovens, placing his ovens in groups of two or three, as at A, B, fig. 85. There are openings near the top of the chamber, C, through which the gases pass into the flues D, thence through E into the flue R, under the ovens B, in which the gases are burnt from the ovens A, the flame ultimately passing away to the chimney. This invention due to Coppée is the first practical attempt to heat the walls of the ovens uniformly up to the top, and to carbonise the coal in a narrow oven. The method of procedure in this oven is practically the same as employed in the present coke oven, or what is termed a " waste heat " oven, where after the ovens have been heated the waste heat is utilised for raising steam in boilers situated in the passage of the hot gases from the ovens to the chimney. The principle of heating an adjacent oven by the gas supplied by its neighbour is one by which a fixed thermal value may be obtained, and a regular uniform temperature maintained in all the ovens, a matter of the utmost importance. In the patent specification Coppée states :—

" Supposing the ovens to be discharged after forty-eight hours working, the ovens, A, will be discharged twenty-four hours after the ovens, B, have been charged ; this will allow of the flames from the several ovens, B, heating their adjoining ovens, A, during the discharging and charging. The gases from the ovens of each pair descend into the passage R (fig. 85), where they unite. The flame from the oven, B, lights the gases from the oven A, and so on alternately. The combined flames of the two ovens then pass along the passage, R, throughout its whole length, thence they pass into the passage R^1 (fig. 86), and returning through the whole length of this latter, issue through openings either into the common gallery G, which communicates directly with the

Fig. 85.—Cross-Section of " Coppée " Horizontal Oven.

chimney, or into the gallery, G^1, and then into the chimney, but during this passage heating the boilers for raising steam.

"As a modification of the above described arrangement, I propose to group the ovens together in threes, as shown at fig. 85, and to make the combined gases of the first two heat the third oven. The gases after passing under ovens Nos. 1 and 2 enter the flue under the floor of No. 3, and when they have traversed the flue they rise to a side flue to heat one side of the oven. The other side is heated by the gases passing off from No. 1 oven of the second group. The gases and liquid products from the coal with which No. 3 oven of the several groups is charged may be collected by the ordinary means and utilised, while the gases from the other ovens after heating No. 3 go to the production of steam, as in the first described arrangement."

Another modification of this oven is described in the specification, but no details are given of its application, that is, as stated above, "the gases and liquid products from the coal with which No. 3 oven of the several groups is charged may be collected by the ordinary means and utilised, while the gases from the other ovens after heating No. 3 go to the production of steam." It further states that L, L, fig. 85, are tubes for the purpose of "serving for the escape of the gases into the atmosphere; M (fig. 85) are pipes for the introduction of cold air; M^1 are pipes for conveying hot air to the ovens in jets through small holes P, P," fig. 86. It is, therefore, difficult to see how by-products could be obtained from the gases allowed to "escape into the atmosphere," by the only means (pipes L) for their escape from the ovens unburnt. On the other hand, provision is made as above described for the admission of hot air, and cold air, for the purpose of burning the gases in the vertical flues, in the walls of the chamber; the gases burning downwards, required a good draught to draw the flame down, and through all the flues to the chimney, entailing losses, which no doubt were soon discovered. There is also the other difficulty to be noticed in this invention, which has to be overcome in drawing all the supply of air and gas from one common source, and delivering the products of their burnt gases into a common exit flue. Anyone who has had any experience in gas-heated furnace practice will know how difficult it is to control the draughts in a series of flues if they draw their supply of gas and air from a common source, and to direct them evenly over a series of flues in the walls of an oven, and thence into one common exit. The fact is, that gases when heated, in their exit from a flue or combustion chamber, take the line of least resistance, and the shortest cut to the chimney, heedless of any other route that may be available. *It is this law that governs and regulates all furnace design.* When, however, furnaces are designed in ignorance of this principle, troubles are sure to arise, and innumerable instances are evident in all departments of furnace work coming under the notice of the author, where this law has been completely ignored. There is another law, which is often neither regarded nor perhaps sufficiently understood; it is, that *hot gases, being lighter than cold gases, or cold air, tend to rise,* and by this law the chimney draught is secured. When

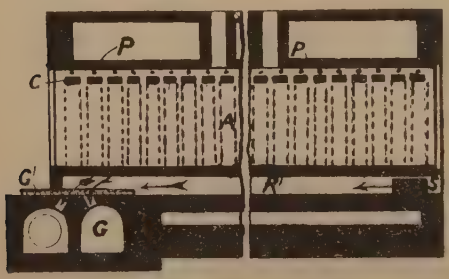


Fig. 86.—Longitudinal Section of "Coppée" Horizontal Oven.

these laws, and the circumstances governing them, are fully appreciated and observed by the furnace designer, a great deal of the waste of fuel, and destruction of furnace brickwork, will be avoided. Furnaces are constructed for a certain purpose—that is, to oxidise the carbon on the grate, or the hydrocarbons in the gases, for the purpose of using the heat developed by the chemical action between carbon, hydrogen, and oxygen. The purpose now under consideration is for the manufacture of coke, and furnaces or ovens are designed to carbonise the coal, and as this process is carried on, gases are generated and given off, which when burned suitably heat the ovens to carry on the process. In the oven now under review, these first principles of the law of gases have not been fully realised, and perhaps the difficulties attendant upon the non-observation of these principles are responsible for the early adoption of horizontal flues to heat the coke ovens, as described by Luis.

The horizontal flue is much more simple to regulate than the combined vertical and horizontal flues as proposed by Coppée, there being only one flue, with one entrance for air and gas, with a straight-forward draught towards the exit to the chimney; there are no other short cuts for the hot gases to take, and a single damper on the air inlet is often sufficient to make all the adjustment necessary for conducting the heating of the ovens. On the other hand, in dealing with vertical flues springing from a common supply flue, if any kind of heating success is to be realised, it can only be obtained with an elaborate system of dampers and valves, to check the draught from following the shortest route along one series of flues to the partial or total neglect of others. In many systems of furnaces, these flues with dampers are arranged so as to guide the heat into the desired quarters, but it is extremely difficult to accomplish with anything like perfection, so that all the heating surface of the walls of the coke oven can be heated to a uniform temperature.

Beyond this matter of draught, there is the other consideration of distance from the source of complete combustion, and some elaborate schemes have often been proposed whereby the gases intended to heat large masses of flues have been supplied with air during their journey through the length of the flues by admitting it at regular intervals, so that the combustion of the gases is continued over a great length of flue. When vertical flues are used in coke ovens of the horizontal type, they are at the most only the height of the coking chamber, and as these flues are necessarily short in comparison with the length of the wall to be heated, usually 33 feet, a large number of flues are necessary. It will, therefore, be apparent, that to heat a wall between two coking chambers such as shown on the Coppée primitive coke oven (there are at least 25 flues shown on the drawings attached to the patent specification) would be extremely difficult; the heat would certainly rush up the flues nearest to the source, and most direct to the chimney flue, since it is impossible to work dampers inside the hot furnace walls of this oven; there is no mention of dampers or valves being used to control the gases from the oven into the combustion flues, consequently there is nothing to prevent the draught in the flues nearest to the chimney drawing a larger share of gas from the oven than those flues farthest away; it is thus possible that the more distant flues would be quite denuded of heating gas, from this cause. Vertical flues can only be depended on to carry out their proper functions efficiently when they are employed singly and separately, and individually are under complete control as to the air and gas supply.

Evidently Coppée at this time was not convinced as to the adequate heating capacity of his system of flues, or of the advantages of coking the coal in an

air-tight compartment; as it will be observed he provides "M^1 pipes for conveying hot air to the ovens in jets through small holes P, P" (fig. 86). These small holes are in the roof of the coking chamber, and air admitted here will not only burn the gas prematurely in the top of the coking chamber, before it descends down the flues, but will tend to burn the coal charge in the coking chamber also; perhaps he thought that this was necessary, otherwise he could have directed this hot air jet into the flues direct to meet the gas from the ovens. A series of air-heating pipes is provided, on the upper part of the roof of the oven, for the purpose of supplying heated air for this purpose, as at "M^1 (fig. 85) and at M for the supply of cold air." It is not stated for what purpose the cold air is supplied, as distinguished from the hot air supply; the introduction of the latter is reasonable, from the fact that more perfect combustion is secured with hot air.

From what has been stated above, it seems clear that the idea of internal combustion of gas, tar, and the top layer of coal in the coking chamber was considered necessary to finish the carbonisation of the coke, and no doubt it was, as the difficulty of uniform heating with the methods described would justify. Nevertheless, a great number of experiments and improvements were made by several coke makers in the direction of obtaining complete combustion in the flues, and uniform heating along with high temperature, but it was not till about twenty-one years after the invention above described was patented that Mr. Coppée made his further improvements in coke-oven construction, and from a study of this invention it will be gathered that the struggle was with the vertical flues and their draughts (B.P. 16,154, A.D. 1899). In the preamble of this patent he states what he considers the object aimed at, as follows:—

"The object of the present invention is to realise the following conditions:—

"1. Circulation of the gases permitting the coke oven to act either with or without the recovery of the by-products.

"2. Retention of the vertical flues and in general the tried construction of the usual Coppée oven.

"3. Introduction of the gases chiefly into lower parts of the oven, principally under the floor, in order that the greatest heat may be produced in these parts and that the heat in the higher parts shall not be great enough to decompose the light oils which are evolved from the coal in the oven.

"4. Distribution of the inlets for the gas and air in several places easily accessible, so as to have a uniform heat in the middle and at the end of the ovens.

"5. Division of the draught in the flues of the ovens so as to be able to regulate at will and separately the draught of the gases and of the air introduced on the front and on the back of the ovens in these flues."

It will be clearly seen that the obstacles confronting Mr. Coppée in his previous invention are got over in this, to a certain extent. Fig. 87 shows a great improvement on the invention of 1868, in so far as the gas is conducted to the combustion-flues, and in the arrangement of the flues themselves. Coppée states that in an oven where the by-products are not collected the gases evolved from the coal in the oven issue from the upper part of the oven by six openings, *k*, fig. 87, enter the four chambers *p*, where they pass by the horizontal openings, *p'*, fig. 88, and descend the wall by the four openings *l*, and the two openings *j*. The gases issuing from the two openings, *l*, arranged in the front part (on the left hand side) of the oven descend in the wall by four vertical flues, *p*, *g*, *q*, *t*, to the chamber *f'*, pass through *c'*, fig. 87, under the floor of the oven by chamber S,

in order to heat this floor, and ascend again in the wall by four vertical flues. *d*, *c*, *f*, *y*, fig. 88. In the back half (on the right-hand side) of the oven the gases issuing from the two openings, *l*, provided in this part, descend by four vertical flues, *p*, *g*, *q*, *t*, to the upper part of a chamber *w*, and thence by *d'*, which is

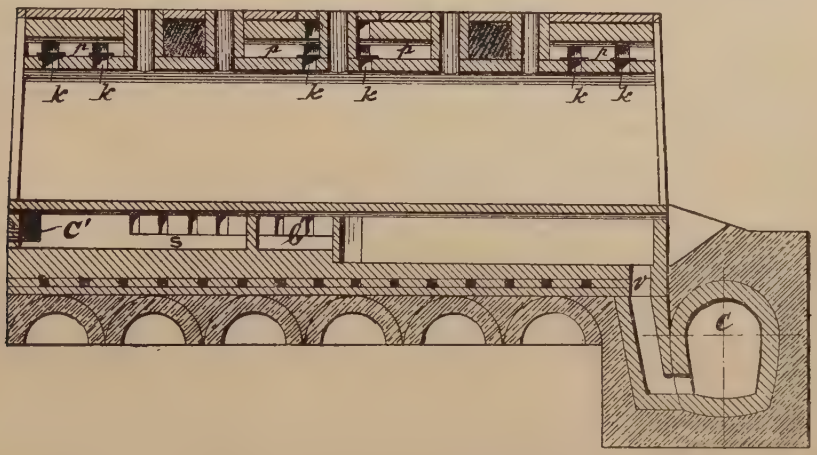


Fig. 87.—Longitudinal Section through Coking Chamber of " Coppée " Oven.

open to S', under the wall, whence they ascend directly in the partition by four vertical flues, *d*, *c*, *f*, *y*, into a chamber V ; here the gases mingle with those from the passage *j*, and the mixed gases descend a series of vertical flues, *n*, *t*, *o*, into

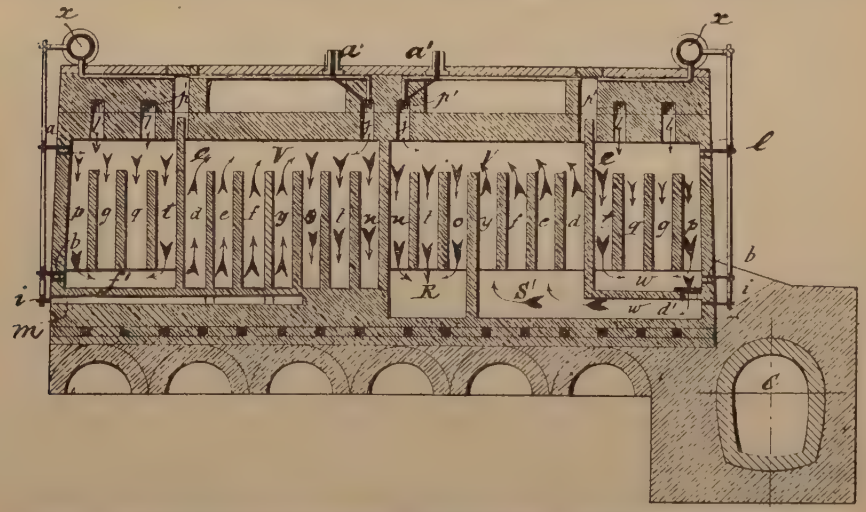


Fig. 88.—Longitudinal Section through Heating Flues of " Coppée " Horizontal Oven.

a chamber R, which communicates with the chimney flue C, fig. 88. In a similar manner the gases issuing from the passages, *l*, at the front of the oven are conducted by flues, *p*, *g*, *q*, *t*, into a chamber *f'*, whence they pass beneath the

oven floor and ascend flues *d*, *e*, *f*, *y*, to mix with the gases issuing from the corresponding passage *j*.

Two sets of flues, one for the front and the other for the back of the oven, are separated by a partition wall, thus dividing the area to be heated. This invention can also be worked for the purpose of recovering the by-products, and for doing so the inventor proposes the following two methods. The gases are withdrawn from the ovens by pipes and conducted through the condensing apparatus, where the residual gases pass along pipes, *x*, fig. 88, placed above the ovens, and provided with branch pipes *l*, *b*, *i*, which are fitted with stop-cocks, and communicate with the heating flues. According to one method of working:—

"The introduction of a small portion of gas, as well as of the air necessary for its combustion, takes place at *l*. In the front half of the ovens the gases descend by four vertical flues *p*, *g*, *q*, *t*, and pass under the floor by the opening C^1, fig. 87, where they meet the gases introduced directly under the floor.

"After having taken a sufficient quantity of air into these parts by a flue *m*, the gases ascend the vertical flues *d*, *e*, *f*, *y*. In the horizontal flue V, which in this part of the oven extends above the vertical flues, they meet an extra quantity of gas and fresh air introduced by the openings *j*; the air is there supplied by the air inlet a^1. The gaseous mixture introduced by a^1 and *j*, descends by the vertical flues, *o*, *t*, *n*, into the flue b^1 under the floor, fig. 87; then by the flue *v*, furnished with a regulating valve, into the great waste heat channel C, and then to the chimney.

"In the rear half of the oven the gases introduced at *l* descend by four vertical flues, *p*, *g*, *q*, *t*, into the upper part of the chamber *w*, divided into two parts by a horizontal partition.

"At the end of this chamber the gases descend by the opening d^1 into the lower part of the chamber *w*, where they meet the gases introduced at *i*; they ascend together by four flues, *d*, *e*, *f*, *y*. In the horizontal upper part, V, they mix with the gases introduced at *j*. This mixture descends by three flues, *o*, *t*, *n*, into the chamber R, then passes under the floor, and thence by the flue, *v*, provided with a regulating valve, to the waste heat channel C, and then to the chimney.

"In the second mode of working, the dampers which divide the upper horizontal flues are now raised.

"In the front part of the oven, fig. 88, the introduction of the gas and air for combustion is at *b* into the chamber f^1 in the lower part of the wall. The products of combustion ascend by four flues, *p*, *g*, *q*, *t*, pass along the upper part above these vertical flues, meeting the gases, which, being introduced at *i* ascend by four vertical flues, *d*, *e*, *f*, *y*, after receiving the air necessary for their combustion by the flue *m*. The mixture of gases from *b* and *i* meets the gases introduced at *j* mixed with the air for combustion entering by the inlet a^1. The products of combustion of the gases from *b*, *i*, *j*, descend again by three vertical flues, *o*, *t*, *n*, pass under the floor, thence through the flue, b^1, to the flue, *v*, provided with a regulating valve, and then to the waste-heat channel C, and to the chimney.

"At the rear of the oven the gas is introduced at *b* under the wall into the upper part of the flue *w*, the valve now covering the opening d^1; with the air for combustion, the gases ascend by the four vertical flues, *p*, *g*, *q*, *t*, and pass along the upper part, V, of the wall above the vertical flues. The gas introduced at *i* with the air for combustion passes into the lower part of the chamber *w*, ascends by the four vertical flues, *d*, *e*, *f*, *y*, until it meets the gas introduced at *b*.

"The mixture of gases from *b* and *i* then meets the mixture of gas and air introduced at *j*. The products of combustion from *b*, *i*, *j* descend by three vertical flues, *o*, *t*, *n*, to R, under the floor, thence by the flue provided with regulating valve to the waste-heat flue, C, and to the chimney."

That these arrangements did not prove entirely satisfactory is shown by the fact that in 1902 Coppée made some other improvements, B.P. 23,544. In the preamble of the specification he refers to his former patent, and states :—

"This invention relates to improvements in the arrangement of coke ovens described in Specification No. 16,154, of 1899, having for their object a better distribution of the points of introduction of gas and air, *to ensure still greater uniformity of temperature throughout the length of the ovens and to achieve a more perfect regulation of the gas and air introduced both at the front and the back of the oven.* These improvements are effected by the following characteristic arrangements.

"(1) Identical construction of the half of the wall in front and of the rear half, the partition compelling the gases to follow identical courses both at the front and at the rear of the oven, the circulation of the gases under the floor being, according to the circumstances, as follows :—Half under the front part and half under the back part of the floor, each half subsequently entering separately a collecting channel, when the oven has two such collecting channels ; or in variable and adjustable proportions according to the necessities of the mode of working, when the oven has a single collecting channel and is arranged for the return of the gas or for its subdivision under the floor.

"(2) The arrangement in the front and the rear of the oven at the lower part of the wall of a canal for introducing a mixture of gas and air which is brought without loss of heat to the part of the flues in the wall where it should burn, in combination with air inlets in the foundations of the oven bringing to the said part the air necessary for complete combustion.

"(3) Special arrangements for working the oven with recovery of by-products, whereby the gas and air introduced under the walls of the oven are mixed in variable proportion as may be desired to prevent formation of graphite near the ports and to ensure complete combustion and a uniform and adjustable temperature throughout the length of the oven.

"(4) Tunnels or conduits formed in the foundations of the oven and accessible by vaults in these foundations for cleaning the distributing ports for the mixture of gas and air in the combustion chamber."

It will thus be seen that the difficulties encountered in working horizontal coke ovens with vertical flues in these early days of their development lay in the complete combustion of the gas in the flues and the uniform heating of the coking chamber ; with the vertical flues the arrangements were rather complicated, requiring various adjustable dampers, and other apparatus, the practical working of which is here described :—

The dampers, *y*, are closed, as shown in dotted lines in fig. 90, the gas evolved from the coal passes in the upper part of the oven through the four openings *v*, the valves in which, shown in the drawing, fig. 89, are in this case raised ; the gases thus enter the chamber *p*, whence they pass into the wall by the four chambers, p^1, fig. 90, and then passing through the openings, *l*, fig. 90, descend into the partition by 18 flues *i*, of which 9 are in front and 9 behind. The gases thus arrive in the chambers, *f*, to ascend 8 flues, i^1, 4 of which are in front and 4 behind. The two currents of gas thus reunited then descend by six flues *j*, and pass beneath the floor, where they depart by flues *n*, fig. 89, in the front half and by flues, *k*, in the rear half to the collecting channels X, X.

Where the oven has only one collecting channel with a return passage for the gas, the progress of the gas is the same as in the previous case up to the point where it descends by the six flues *j*; it then passes under the floor, where it

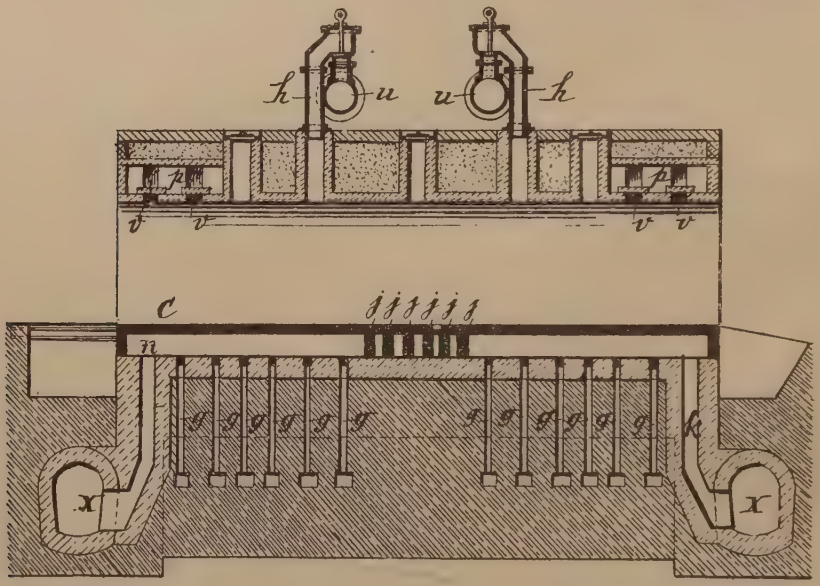


Fig. 89.—Longitudinal Section through Coking Chamber of "Coppée" Horizontal Oven.

meets the gas from the neighbouring oven, to be turned in proportions suitable for the mode of working, one part directly to the flue, *n*, of the oven, the other

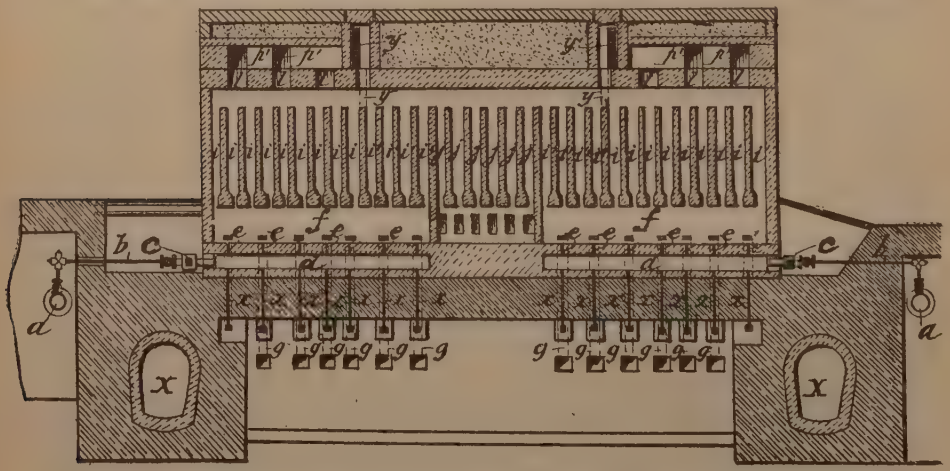


Fig. 90.—Longitudinal Section through Heating Flues of "Coppée" Horizontal Oven.

part towards the front of the oven to pass under the floor of the neighbouring oven through the gas return passage, and thence through the flue, *k*, to the waste-heat flue. This arrangement, by which the ovens communicate in pairs

underneath the floor, allows regulation of the draught before and behind the oven in the flues.

Working with recovery of by-products, the dampers, y', are raised, as shown in fig. 90. The gases pass from the coking chamber into the pipes, h and u, situated above the ovens, fig. 89. They are conducted away to the by-product plant and returned to the ovens by means of the service pipe a, with branch pipes, b, leading to the mixing apparatus, with injectors C, fig. 90; the gas is here mixed with air; the mixture is then passed into the flues d, and into the combustion chambers, f, through the ports, e, e, beneath the chambers f. The air for the complete combustion of the gas enters by the ducts, g, in the foundations of the ovens, and passes into the combustion chambers f, where it meets the mixture of gas and air from the flue d. The products of combustion ascend the flues i, i, of which there are 13 in front and 13 behind, the heated gases then descend again through the six flues, j, fig. 89, and pass beneath the floor into the waste heat flue X, and thence to the chimney.

Fig. 91.—Cross-Section through Regenerators.

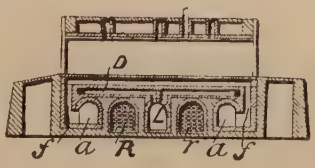
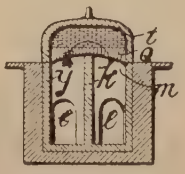


Fig. 92.—Cross-Section through Valves.



The next improvement Coppée makes is with regard to the more complete combustion of the gas; to effect this he pre-heats the air by means of regenerators situated under the ovens; these are so arranged that no reversal of the heating gases in the heating flues is required. The products of combustion, after circulating through the flues of the oven, pass down flues, f, fig. 91, into flues a, which run the length of the battery of ovens, and lead to a distributing pit, y, fig. 93, divided into four chambers by walls k; each of the chambers is provided with openings e. A movable cap, t, is formed with a partition across its centre Q, which when turned to coincide with the wall, k or m, diverts the combustion gases into one or other of the regenerators R or r. Air is supplied by a pipe, C, fig. 93, to a second pit y', and passes along either of the regenerators, R, r, to the pit y, and thence to a flue, L, fig. 91. The heated air from the flue, L, rises into flues D, whence it is distributed to the heating flues. When the caps of the pits coincide with the walls, m, k^1, fig. 93, the products of combustion passing from the flues, a, are diverted into the regenerator r, and then through the channel k, to raise steam in the boiler; the air also passes from the pipe, C, fig. 93, through the pre-heated regenerator r. When the caps are turned to coincide with the partitions, k, m', fig. 93, the combustion gases pass through the regenerator r, and the air passes through the regenerator R. The caps can also be operated simultaneously. In the following year Coppée applies for another patent for the same purpose, B.P. 19,480, A.D. 1908, in which the air for combustion is forced through the valves into the regenerators, which have been pre-heated by the combustion gases; these valves, similar to those

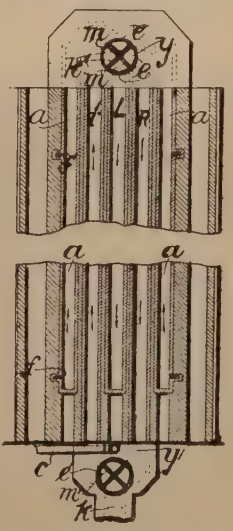


Fig. 93.—Plan through Valves.

"Coppée" Horizontal Coke Oven.

on a Siemens gas producer, are reversed about every half-hour; from the regenerators the air is passed into a collecting and distributing chamber at the back of the ovens, whence it is distributed to the several ovens.

It may be well to mention here, following the development of the Coppée oven, a few facts relative to the heating of vertical flues, and to show by way of illustration in fig. 94, which represents a section through a set of vertical flues, fed from a common heating source in the direction of the arrow. The main horizontal flue distributes to the vertical flues *m*, *l*, *k*, *i*, and in order to show more clearly the direction of flow and its distribution of heat, and its intensity throughout its journey, dotted lines are used. It will be observed that the first vertical flue, *m*, does not secure so much of the heat current as the fourth flue *i*, on account of the impetus of the draught, carrying the current past *m* and striking against the wall at *i*, ascending the end flue, while the flues *k* and *l* take their share in about the proportions shown by the intensity of the dotted lines.

When the horizontal flue at the top of the vertical flues is reached by the current, and the downward course is commenced, the same impetus given to the current carries it past the first flue and distributes it as shown, down *h*, *g*, *f*, *e*, but in diminished intensity to that which it possessed at *m*, owing to other factors being at work which absorb the heat as it passes through the flues.

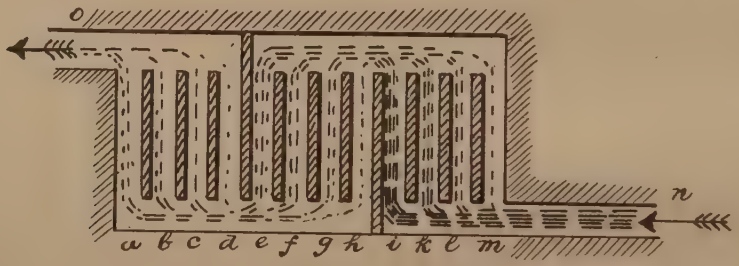


Fig. 94.—Vertical Section through Vertical Heating Flues showing Draught Diagram.

This is shown by the attenuation of the dotted lines; and as it reaches the lower horizontal flue it has parted with a great deal of its original heat. It will now be obvious that all these horizontal and vertical flues cannot be heated to the same degree of temperature at the same time, and this can be verified by looking into a coke oven heated in the manner described and set forth in similar design as in fig. 94, where it will be seen that there are bright and dull patches on the walls where the flues are, indicating the amount of heat each flue is giving out to the oven; these flues nearest the source of heat will be the brightest and hottest. The problem confronting the coke-oven designer is, therefore, designing the flues in the instance shown in fig. 94 by judiciously contracting them when the current is greatest, so that the conduction of the heat current will be equally and evenly distributed, and that every flue throughout the entire walls of the oven will give out the same equal heat, and constantly so, in order to produce the most satisfactory results.

We have traced the Coppée oven in its development up to the point where it is complete in all its details; a description of this oven, together with drawings, has been given to the author by the kindness of the manager of the Coppée Company. They still make two kinds of coke ovens, one termed "waste-heat" oven, and the other "by-product" oven.

Both classes of ovens are by-product saving ovens; the "waste-heat" ovens work at a lower temperature than the second class designated "regenerative" ovens. In the first-mentioned ovens the waste heat is conducted from the ovens to steam boilers for raising steam. The second class of ovens are similar, but the waste heat is used to heat regenerators for pre-heating the air for combustion of the gas in the oven flues, thereby producing a higher temperature and a more complete combustion. The company state, "The advantages claimed for the by-product oven are :—

"1st. An increase of at least 10 per cent. in the yield of coke from any given coal.

"2nd. An increased production of coke per day, owing to the shorter coking period.

"3rd. A lower cost per ton of coke manufactured.

"4th. A substantial profit from the by-products, varying with the quality of the coal used, and the market price of the by-products.

"5th. A smaller area required for the plant for an equal production of coke.

"6th. The production of good coke from inferior coal, which will not coke in Beehive ovens.

"7th. The production of a greater amount of surplus energy either as waste heat or surplus gas."

They state that, "The spare gas available which is not required to heat the flues amounts in these ovens (waste-heat ovens) to from 5 to 20 per cent. of the total yield."

Their "waste-heat" by-product oven is shown in figs. 95, 96, 97, 98, 99. After the by-products have been extracted from the gas, it is returned to the ovens by a main pipe A, placed along each side of the bench of ovens, with separate branch pipes B, each fitted with regulation cocks C, which conduct the gas to the mixing apparatus D, designed on the Bunsen atmospheric burner principle, and which allows a regulated quantity of air to enter with the gas. This mixture is then passed into the distributing channels E, which are situated directly beneath the heating flues of each half of the side wall; thence it passes through the openings, F, into each vertical flue.

The secondary air for combustion enters the conduit, H, from both ends of the battery of ovens, and passes into the flue J, and from this main air flue separate flues are provided to feed each oven. The Company also state that, "By means of these secondary air inlets a regulated quantity of extra air can be separately admitted to each of the vertical flues G," fig. 98, but it is not quite apparent how an exact amount of air and gas can be equally distributed to each separate vertical flue by these means without a separate independent feed being provided for each individual flue, when the ingress is dependent upon the draught of the chimney. The air is heated to a certain extent by its passage along the foundations of the ovens. The cocks for regulating the gas supply and the valves for regulating the secondary air supply are shown at D. The products of combustion ascend the heating flues, G, simultaneously, and reach the top, L, fig. 95; they then descend the flues M and pass into the flue P, figs. 96, 97 and 98, which is placed beneath the floor of the ovens for the purpose of heating it, after which the hot gases pass into the collecting flue Q, which leads through the boilers to the chimney.

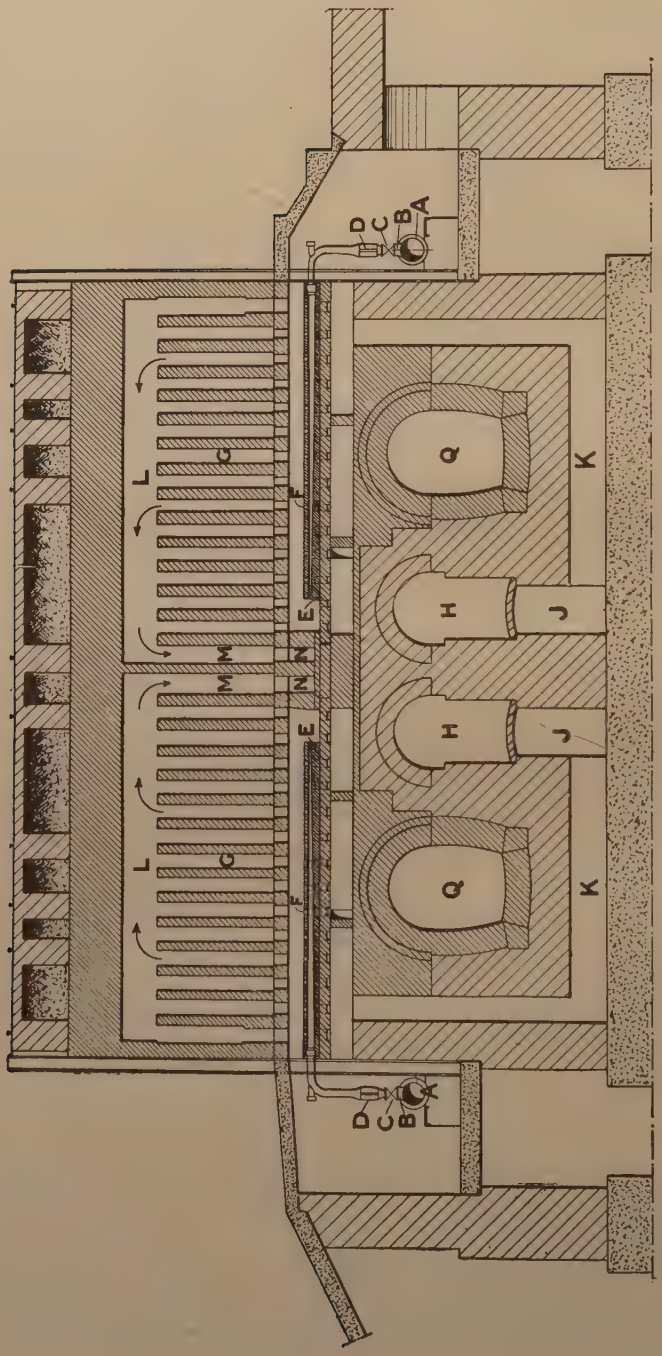


Fig. 95.—Longitudinal Section through Heating Flues. Coppée "Waste-Heat" By-Product Oven.

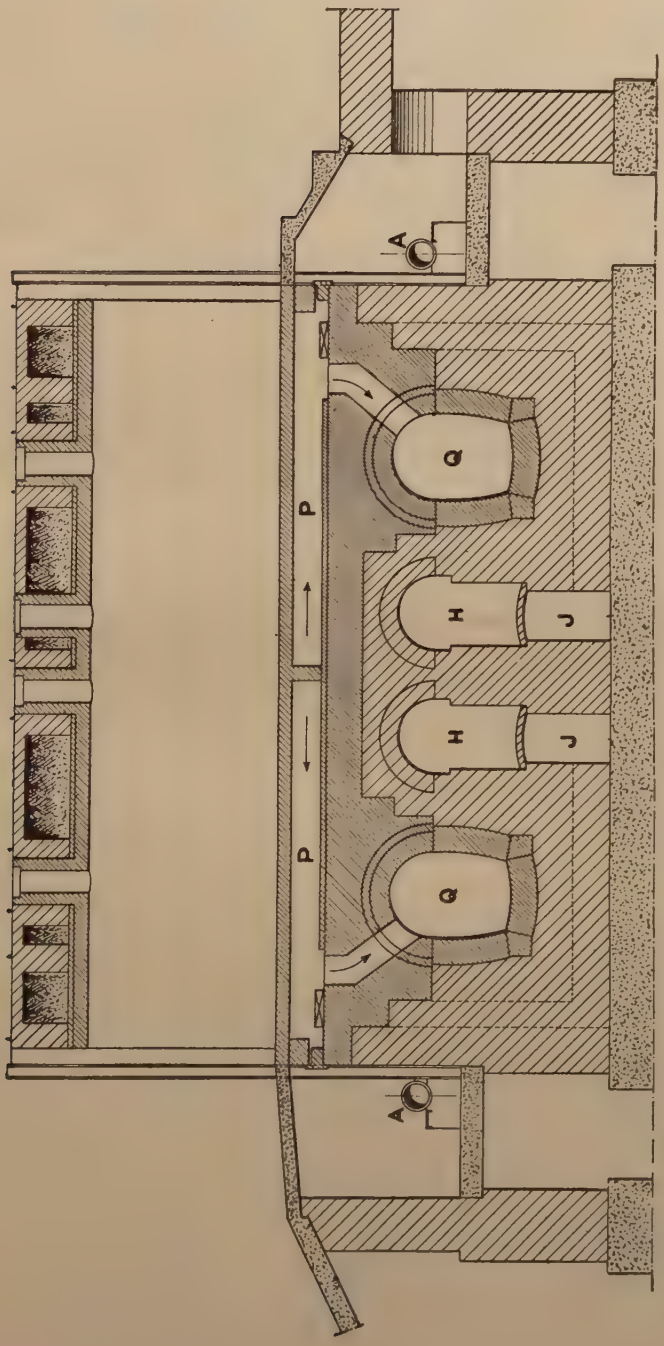


Fig. 96.—Longitudinal Section through Oven Chamber. Coppée "Waste-Heat" By-Product Oven.

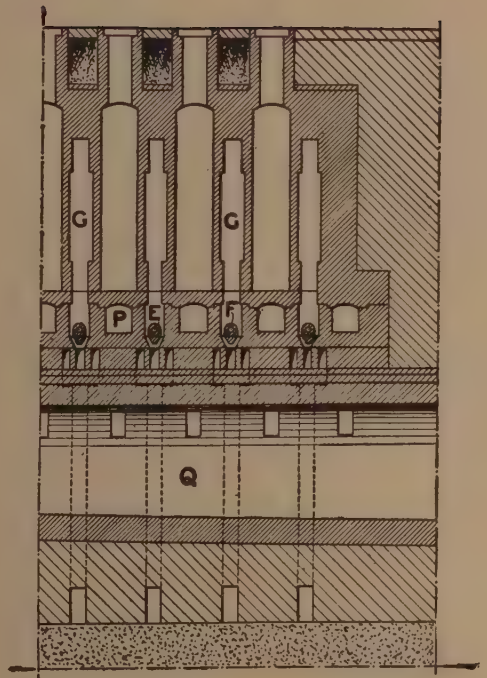


Fig. 97.—Cross-Section through Ovens and Heating Flues.

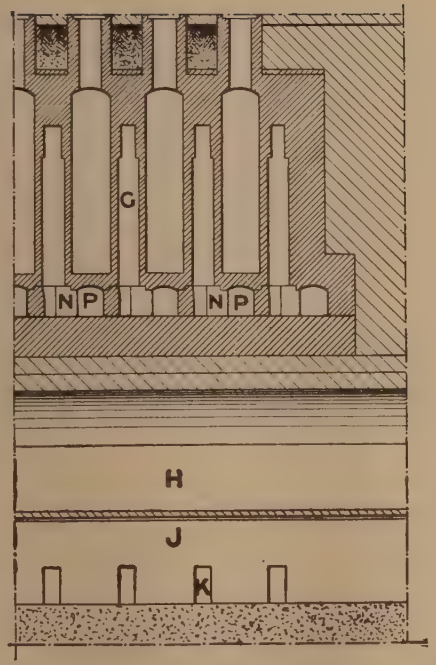


Fig. 98.—Cross-Section through Ovens and Air Conduit.

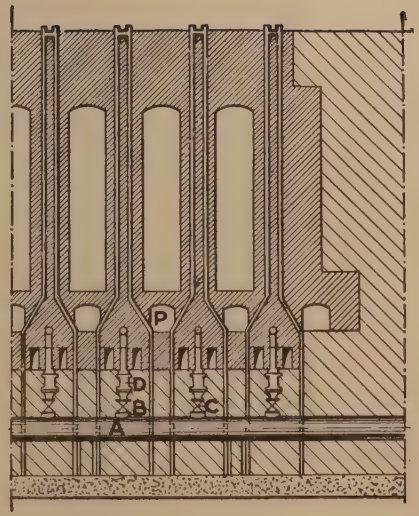


Fig. 99.—View of Ovens showing the Admittance of Gas and Air.

Coppée "Waste-Heat" By-Product Oven.

The regenerative by-product coke oven by the same company is shown in figs. 100, 101, 102, 103, 104. This oven is of practically the same design

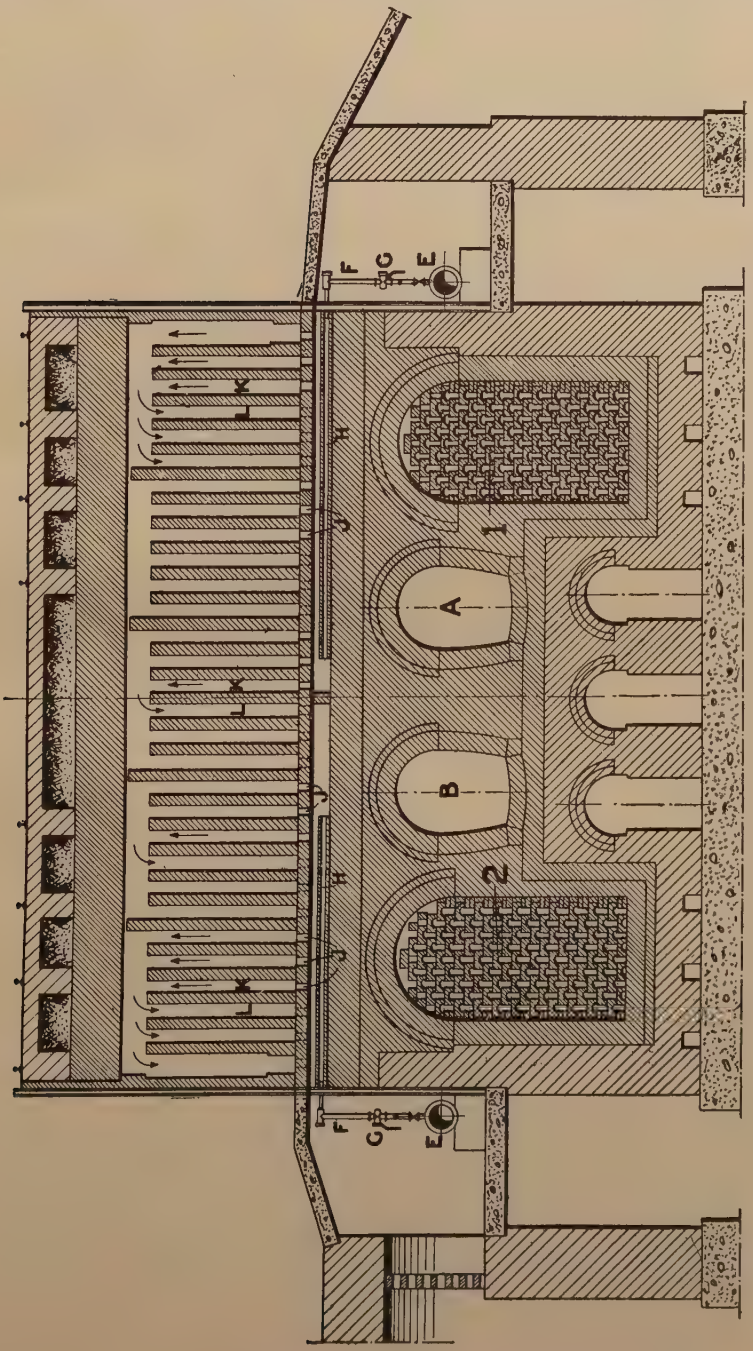


Fig. 100.—Longitudinal Section through Heating Flues. "Coppée" Regenerative By-Product Oven.

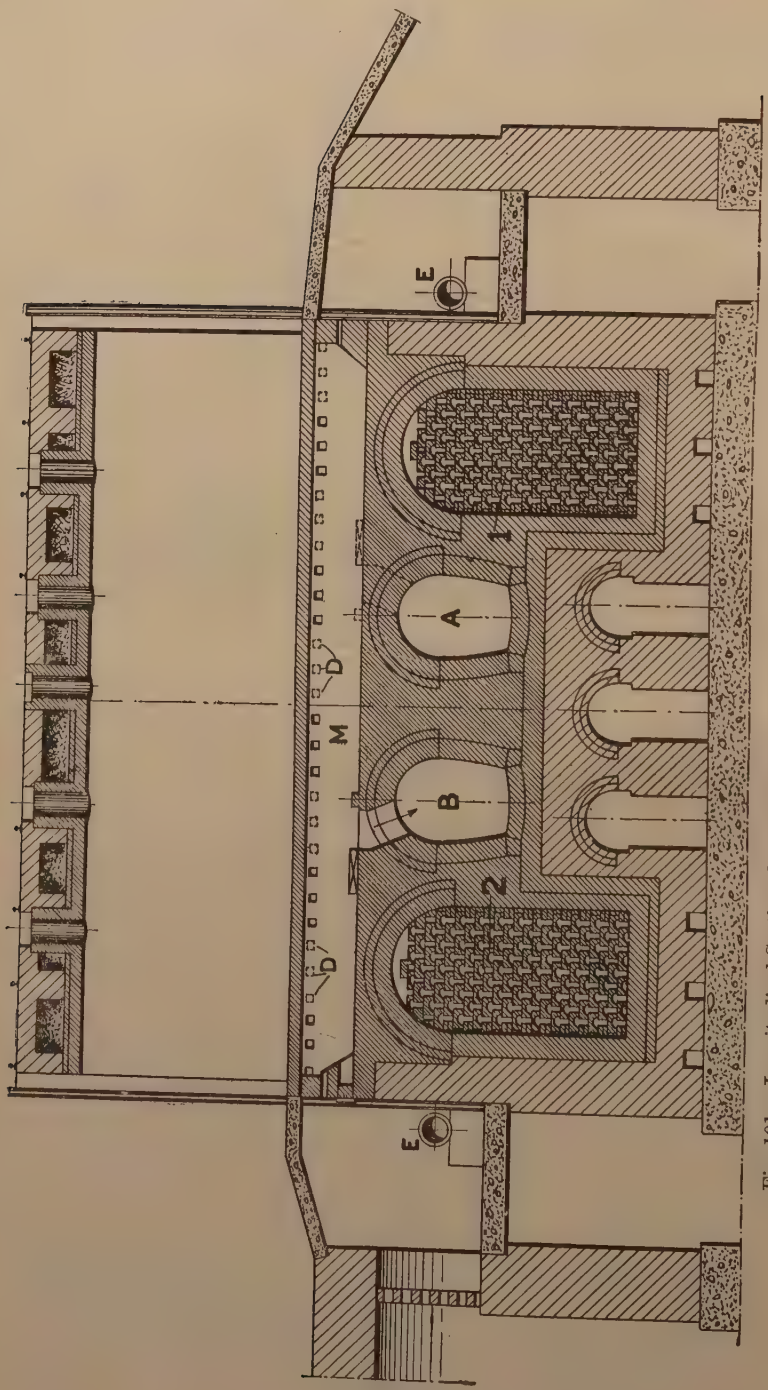


Fig. 101.—Longitudinal Section through Oven Chamber. "Coppée" Regenerative By-Product Oven.

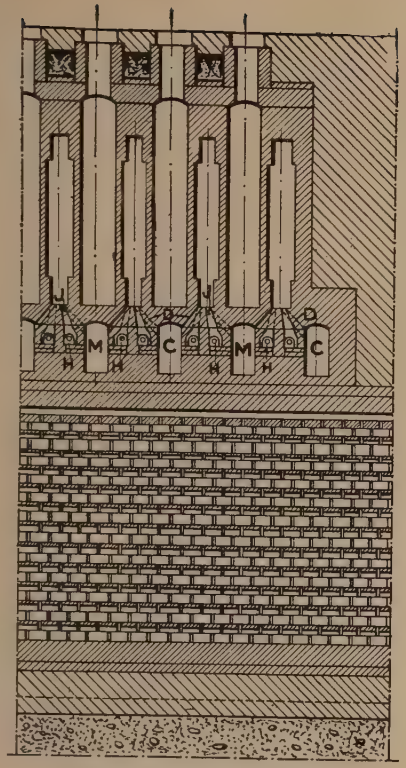


Fig. 102.—Cross-Section through Ovens and Heating Flues.

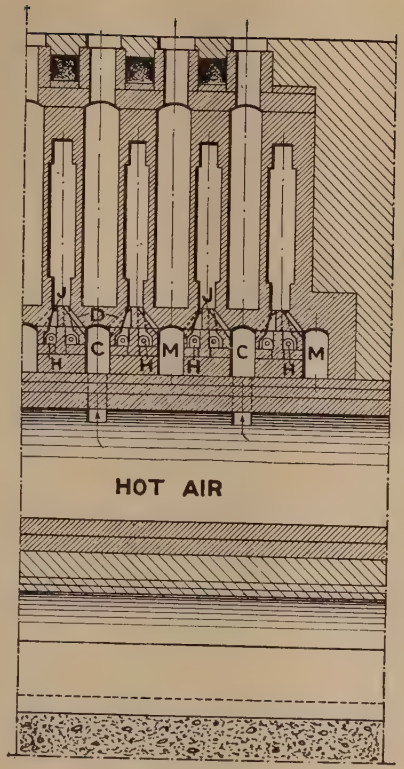


Fig. 103.—Reversal of the Heating Process.

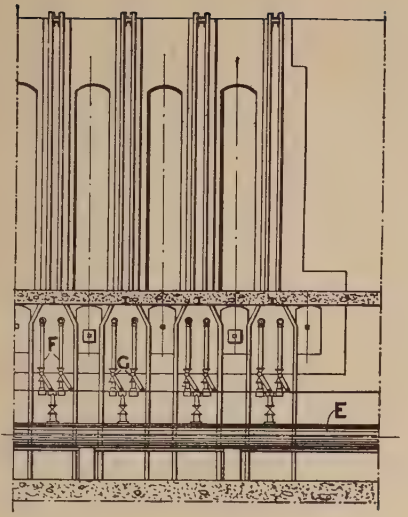


Fig. 104.—View of Ovens showing the Admittance of Gas.

"Coppée" Regenerative By-Product Oven.

as their "waste-heat" oven just described, the only difference is that the air for combustion is heated by means of regenerators placed under the ovens. These regenerators consist of galleries filled with firebricks, stacked in them in such a manner that the hot gases have to traverse the whole of the brick chequer work. The regenerators are worked in pairs during the period of heating, which lasts generally about half an hour; the gases from the combustion flues pass through one of these galleries filled with this chequer brickwork, and heat it up to the temperature of about 1,000° C.; the valves are then reversed, and the cold air for combustion is made to pass through this hot gallery in a reverse direction on its way to the combustion flues, while the other regenerator is receiving the hot gases from the combustion flues. By this method of recovering the initial heat of the burnt gases, the amount of gas consumed in heating the ovens is as a rule reduced to 50 per cent. of that generated in the carbonising process.

A fan is employed for delivering the cold air to regenerator No. 1, where the heat is taken up by the air from the hot brickwork, fig. 101. This heated air then passes on to a collecting flue A, and then enters the sole flue C, fig. 102; the admission of the air is controlled by means of dampers arranged between the regenerators and the sole flue. The hot air then passes from the sole flue into the vertical heating flues, through the openings D, fig. 103. The gas that has passed through the by-product plant is returned to the ovens by the main flue E, fig. 104, which has separate branch pipes supplying the distributing channels H, fig. 103, and each of these pipes has a regulating cock G, fig. 104; the distributing channels are situated directly beneath the heating flues; the gas passes from them through the openings, J, fig. 103, into each vertical flue, where it is burned by the hot air entering through the passages D. The products of combustion pass up the heating flues K, and descend the flues L, fig. 100. They then pass into the sole flue M, beneath the floor of the oven on the right-hand side of the heating flues, fig. 102, and are from there delivered into the collecting flue B, fig. 101, and from there through the regenerator No. 2 to the chimney.

In this oven the heating flues are divided up into five sections, each containing six vertical flues; these six flues are also divided into two groups, K and L, which act alternately, as, for instance, combustion flues L, and exit flues K, for the burnt gases; and *vice versa*, when the flues L are used as heating flues, the flues K are the exit flues, so that by this arrangement only half of the flues on one side of the oven are combustion flues, to which gas and air are admitted for the period of about half an hour, until the commencement of the second period; when the regenerator valves are reversed the heating flues are also reversed, and become thereby the exit flues. This is accomplished by means of the dampers and regulating cocks G, which are simultaneously reversed, along with the regenerator valves; by this means of dividing up the flues into separate sections a good regulation and distribution of heat is secured, as the flues are short, and the up-current is in the heating flues L and the down-current in flues K, or *vice versa*. As the temperature is not very different when the process of reversal takes place every half-hour, a pretty high temperature is well maintained. The dimensions of these ovens are usually 33 feet 4 inches long by 8 feet 2½ inches high, and they are generally charged from trucks through the roof of the oven, or where necessary the coal is compressed and charged with the machine, and discharged with a ram and quenched with the quencher, the coke being delivered into a trolley. The gas is taken off from the ovens by means of the ascension pipe and delivered into

the hydraulic main, which runs along the top of the whole battery of ovens. The apparatus for raising the doors at each end of the ovens runs along the ovens on each side upon rails.

Fig. 105 shows a bench of steam boilers being fired by surplus gas from Coppée by-product ovens.

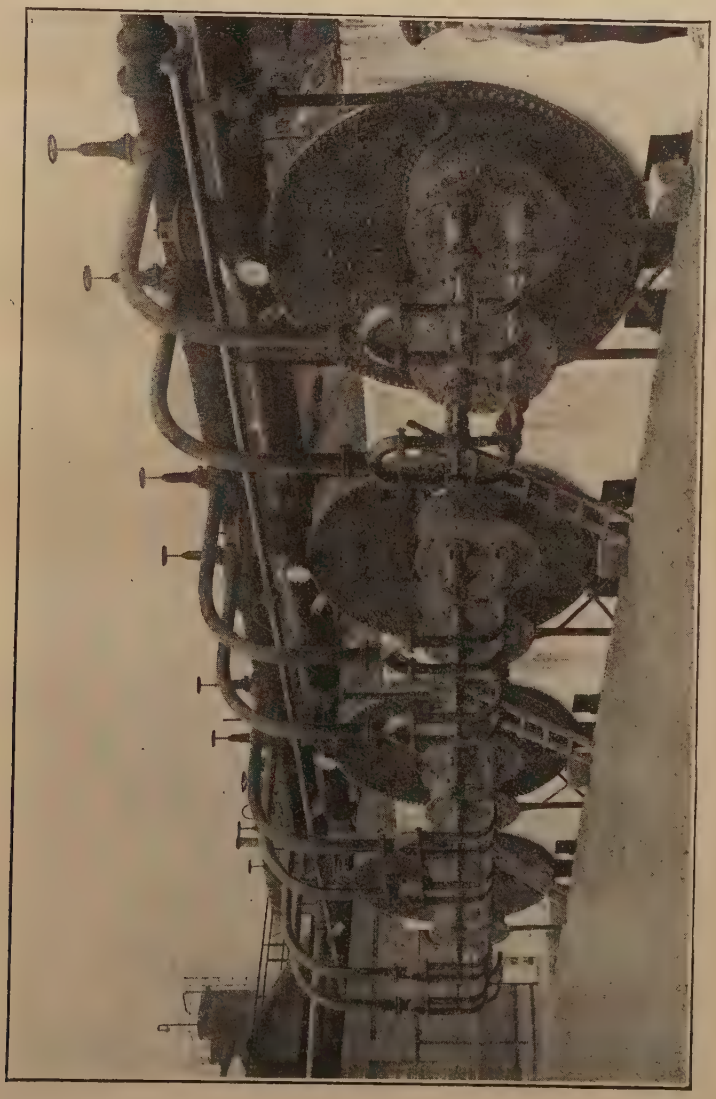


Fig. 105.—Range of Boilers Generating Steam by Coke Oven Gas.

Messrs. Coppée state that " a battery of 50 regenerative coke ovens of medium size will coke 325 tons of dry coal per day. Taking coal of average quality containing 10,500 cubic feet of gas per ton, and assuming 50 per cent. of surplus gas, there would be available 1,706,250 cubic feet of surplus gas per day. Large

gas engines working on such gas have been found to use about 18 to 19 cubic feet per brake horse-power per hour. This quantity of surplus gas would, therefore, develop $\frac{1,706,250}{19 \times 24}$ = about 3,440 H.P., which with dynamos of modern type will produce about 2,750 kilowatt-hours." The company further state that, "using waste-heat ovens and raising steam in boilers by the waste heat, together with high-pressure steam turbines, the battery of 50 coke ovens coking the same amount of coal per day, as above, will raise about 300 tons of steam per day; if this steam is superheated and used to drive steam turbines, the consumption is about 11 lbs. of steam per horse-power-hour. The power produced will, therefore, be $\frac{300 \times 2,240}{11 \times 24}$ = 2,545 H.P., which is equivalent to about 1,870 kilowatt-hours."

With regard to the products from their ovens, they state that the output of coke and by-products is as follows:—

South Wales.	*Coal containing about 22 per cent. Volatile Matter.*	
Coke (total),	77·6 per cent.	= 15·52 cwts. per ton of coal.
Sulphate of ammonia,	1·22 „	= 27 lbs. „
Tar,	4 „	= 90 lbs. „
Benzol,	0·9 „	= 2·25 galls. „

Midlands.	*Coal containing about 34 per cent. Volatile Matter.*	
Coke (total),	65 per cent.	= 13·14 cwts. per ton of coal.
Sulphate of ammonia,	1·6 „	= 35·84 lbs. „
Tar,	4·5 „	= 100 lbs. „
Benzol,	1·2 „	= 3 galls. „

The Otto-Hilgenstock Coke Ovens.—It was about the year 1881 when the Otto-Hilgenstock coke oven was designed, and was first erected in Germany; it was constructed upon similar lines to the Coppée coke oven, and heated with vertical flues, the air for combustion being pre-heated, by means of regenerators. The walls of this oven were constructed with vertical flues, and were divided into two halves, the heating being accomplished by admitting the gases alternately into one half and then into the other. This oven, although worked very extensively in Germany, was rather difficult to manage, owing to the unsatisfactory distribution of the heat. As a consequence of the invention of Gustave Hilgenstock, the coke oven was entirely changed as regards its heating arrangements. The entire arrangement of regenerators was dispensed with, and in their place a system was adopted upon the Bunsen atmospheric burner principle of mixing air with the cold gas previous to its ignition, and burning this mixture by means of burners constructed on the Bunsen principle.

Hilgenstock states (B.P. 6857, A.D. 1896) that the essential feature of his invention is the supply of gaseous fuel to the oven from below, and for rendering this possible and accessible to workmen for the purpose of regulation and adjustment, conduits are provided under the ovens. Figs. 106 and 107 show a longitudinal section and a cross-section respectively through a bench of coke ovens heated upon this plan; the gas is brought from the by-product plant by the gas mains, having branch pipes *g*, which are constructed inside the conduits or tunnels R, each of which branch pipes supplies a separate section of four vertical flues, or by multiplying the number of branch pipes each vertical flue could be separately supplied; by this means a very uniform temperature can be attained throughout the oven.

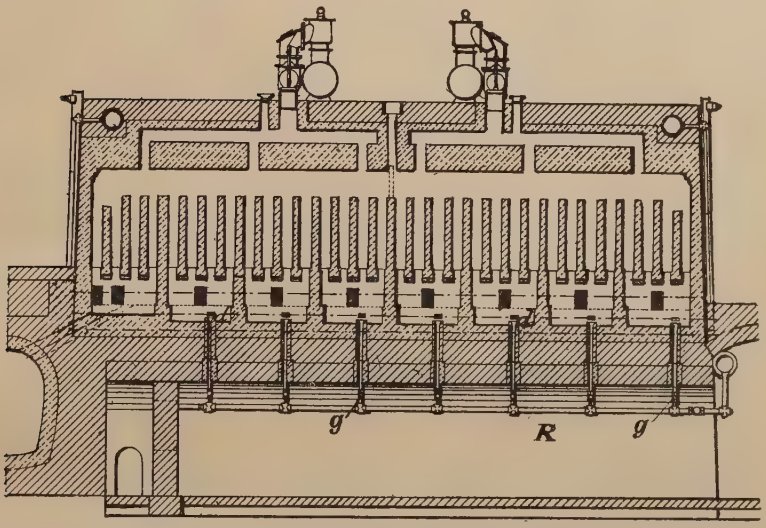


Fig. 106.—Longitudinal Section through Heating Flues of " Otto-Hilgenstock " Ovens.

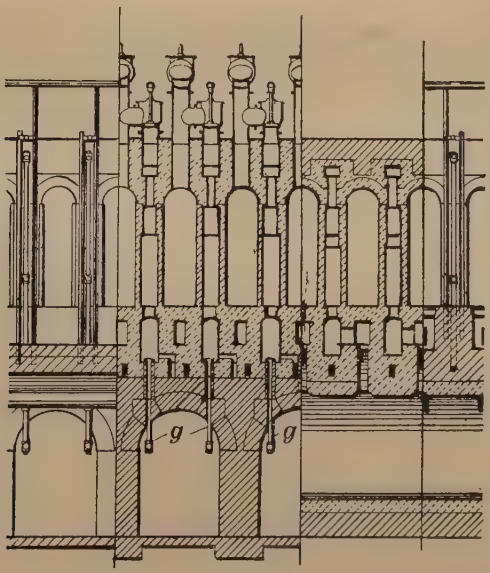


Fig. 107.—Three Cross-Sections through Heating Flues of " Otto-Hilgenstock " Oven.

The latest type of Otto regenerative by-product oven is shown in fig. 108. A description of these ovens and drawings has been given to the author by the kindness of the manager of the Otto Co.

Referring to fig. 108 as the type of waste-heat by-product oven, it shows a marked advance in the practical heating of vertical flues in horizontal coking

ovens, where regenerators are not used, the advance being characterised by the fact that the mixed gas and air can be brought directly under each vertical heating flue, if so desired, and thus avoid the short-circuiting of the heating gases to the exit flue and to the chimney, and giving a very ready and easy adjustment of the gas and air supply to each flue. These " waste-heat " ovens are

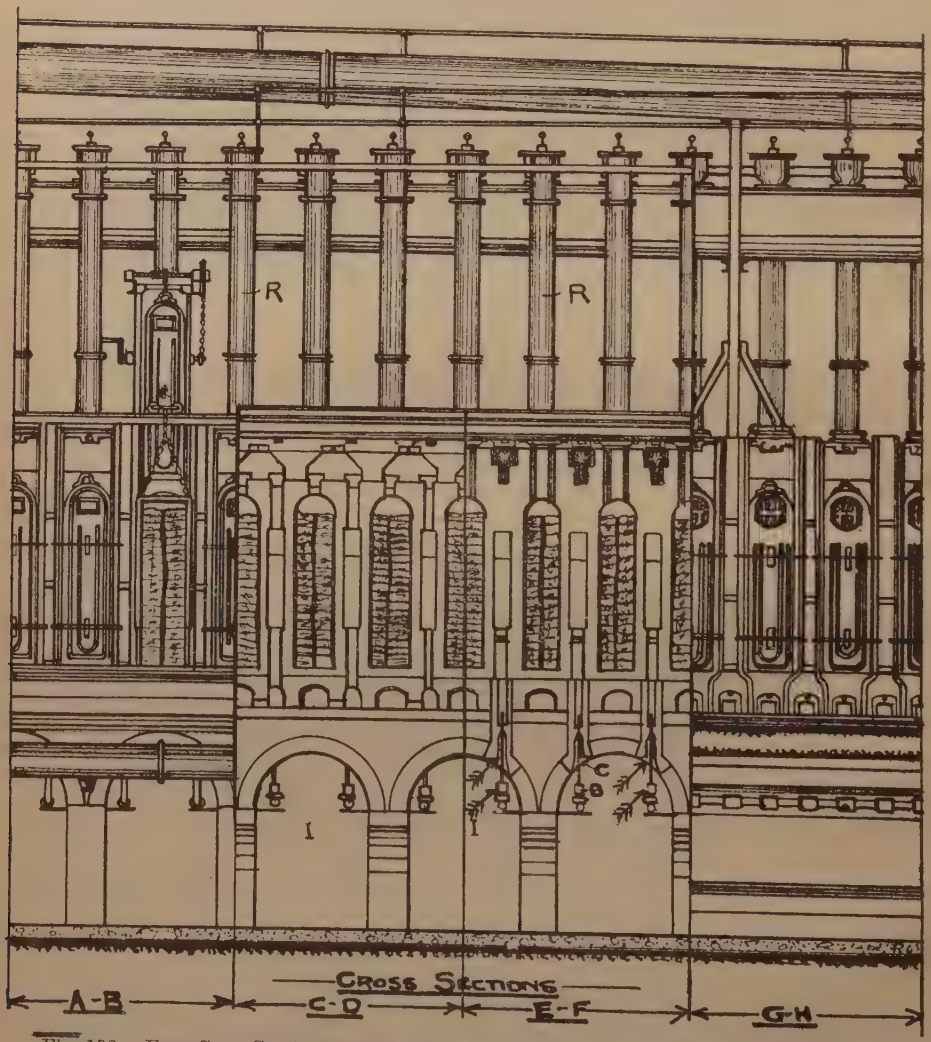


Fig. 108.—Four Cross-Sections and Part Elevation through Waste-Heat Oven of " Otto " Coke Oven.

still being erected at collieries where the surplus gas is not required, and where the waste heat is applied to raising steam in boilers. They claim, with good coking coal having a moisture content of from 8 to 10 per cent., that this oven gives approximately 10 to 15 per cent. of surplus gas after heating the ovens, when they are worked at their normal output.

The gas, in this instance, after leaving the by-product plant, arrives at the ovens in the large distributing mains, A, in the visiting gallery or conduit. From this main distributing centre branch pipes E, figs. 109 and 110, lead to the Bunsen burners. These gas burners are 16 in number in a normal-sized oven, and are constructed as previously stated. The primary air enters the burner at B in the latest forms of this oven, and the secondary air enters at the space between the brickwork and the burner tube at C, combustion taking place at the end of the burner brick at the point D, fig. 109. The heated products of combustion ascend the vertical flues into the horizontal inspection flue *e*, and travel in the direction shown by the arrows down to the end of the vertical flues at the pushing engine side, into the waste-heat flue G. The gases in the vertical flues being at a temperature of about 1,200° to 1,400° C., and being at 1,100° C. in the waste heat connecting flue G, arrive at the boilers at slightly over 1,000° C. The ovens are so constructed that they will easily work as non-by-product ovens. In this case the gas passes through a port-hole in the roof of the oven, and is directly by-passed into the top of the horizontal flue, where it meets the required quantity of air, and proceeding down the vertical flues, then along the sole of the oven, makes its exit into the waste-heat flue by means of the chimney draught, an arrangement not to be recommended where it is possible to employ the method described above, that of burners.

On batteries of over 50 ovens a charging machine is recommended, in order to do away with hand charging, and is worked on the pushing ram principle. The doors of the oven are raised by means of a crane, T, fixed on the ram, fig. 110. By constructing these ovens on arches, as shown in figs. 109, 110, 111, every burner is approachable and easily cleaned. The arrangement also has the great advantage that the burners can be regulated, therefore obtaining a very uniform temperature in the walls of the oven throughout their full length by the combustion of the gas at the burners, which are placed at suitable and regular distances apart. The ram pushes out the coke when finished on to the sloping bench through the quencher W, fig. 110. Three different kinds of coke benches are used for the following different purposes :—

1. A sloping bench designed for hand-loading into trucks.
2. A sloping bench for carrying the coke away in a car.
3. A bench made so that the coke falls into a coke conveyer.

The first of these forms is shown in fig. 109 at K. The second is shown in fig. 111, K^1, where the coke is pushed through the quencher directly into the car L, which runs alongside the coke ovens, and the third is shown in fig. 110, where the coke is pushed through the quencher, W, on to the sloping bench K^2 and into the travelling conveyer, working automatically at the bottom of the bench at M. The surplus quenching water is drained off into a channel running along below the several kinds of coke benches.

Fig. 110 also shows the method of charging the ovens from the top (apart from the charging apparatus on the ram), by means of the travelling apparatus S, which serves all the ovens, and consists of a bunker of coal, with shoots at the bottom, which deliver the coal into the three charging port-holes in the roof of each oven. In this case the doors are actuated by the travelling crane T. The exits for the gas are shown at R, R, figs. 110 and 111, where they are connected to the hydraulic main at P, from which the gas passes to the by-product plant.

The Otto Regenerative Oven.—The Otto by-product regenerative coke oven is constructed on arches, with the same facilities for supplying gas and for

regulating its supply by means of tunnels or conduits, into which the attendants can enter for the purpose of adjustment of the gas supply, cleaning the tubes, and for inspection, as in the case of the waste-heat ovens already described.

The gas, however, in this class of oven, after leaving the by-product plant, is brought back to the ovens in the mains along the middle gallery A, figs. 111 and 112. It is distributed from this main by means of branch pipes, O, to right and left, with vertical branches C, C_1, which ascend into the several vertical combustion flues, and the gas mixes with the pre-heated air entering at the port holes E, fig. 112, and being ignited, burns approximately at the point, F, in each combustion flue. The cold air enters through the port hole, L, fig. 111, passes down an annular space, following the arrows, into the bottom of the regenerators J, where it is heated and ascends through the regenerators into the channel conveying it to the combustion chambers.

The products of combustion in the flues ascend the vertical flues G, and enter the horizontal inspection flue H, and then descend the vertical flues, I, on the left-hand half of the ovens, fig. 112, passing out of the bottom of these flues through the port-holes K, whence they pass through the regenerator, J, fig. 111, on the opposite side, heating up the chequered brickwork in it as they descend and flow away through the bottom channel into the chimney flue. By this means the temperature of the hot products of combustion is reduced in the regenerators from about 1,150° C. down to 258°–300° C. before they pass away to the chimney shaft.

After thus working for a period of about twenty minutes, the gas is cut off until the air is reversed, and the whole process of heating proceeds in the opposite direction. That is, the air is now being heated up by entering the regenerators on the other side of the oven, and passing up through the air ports, meets the gas in the vertical combustion flues now on the other half of the oven, which before the reversal of the air were the flues by which the products of combustion made their downward exit to the regenerator, but now are the combustion flues. The products of combustion, ascending into the horizontal inspection flue, H, proceed downwards through the vertical flues, which previous to the reversal were the combustion flues, and in the reverse way to that shown by the arrows in fig. 111, through the regenerators into the flue, G^1, to the chimney stack. The regenerators are conveniently placed at each side of and under the coke ovens, as at J, J, fig. 111. They are not placed immediately under the ovens for obvious reasons, but under the sides; the flues connecting the regenerators with the chimney stack are also placed at each side and under the ovens, as at G and G^1. The charging of this oven with coal is similar to that already described for the "waste-heat" oven, and the discharging of the coke is performed in a similar manner, as well as the quenching and the subsequent handling of the coke into the several trucks, cars, or conveyers. Similar means are also adopted for the collection of the gas and conveying it to the by-product plant through the hydraulic main P, fig. 111.

The Otto Company claim with normal coking coal, having a moisture content of 10 to 20 per cent., about 50 to 60 per cent. of surplus gas from their by-product regenerative ovens, after providing for the due heating of the oven, and the gas is used both for power purposes and for illuminating gas for towns. A battery of ovens of this character was erected at the Newport Ironworks of Sir B. Samuelson & Co., Ltd., which are supplying the town of Middlesborough with gas for all required purposes—power, lighting, and domestic use.

Soldenhoff's Improvements in Coke Ovens.—Anticipating the application of regenerators for pre-heating the air for the more complete combustion of the

gas for heating coke ovens, R. de Soldenhoff made what he terms the more complete utilisation of the waste heat of the Coppée oven, B.P. 1950, A.D. 1882. His novel method is shown in fig. 113, which is a vertical section through the heating flues, and through his regenerative system.

The space between the bottom of the gas flues, B, and the top of the foundation arch, A, is filled with firebrick chequer work. The cold air enters A and rises by openings, D, to the space containing the chequer work at F, where it is heated; it then passes by the flues, H, G, to the distributing flue, from which it is conducted by the flues situated above the partition walls between the ovens to the combustion flues. A modification provides that the regenerator, F, fig. 113, is divided into two portions, through one of which the air is heated, while the other division is being heated up by the exit of the hot gases as they pass to the chimney flue B. After the regenerator has been thoroughly heated in that half traversed by the hot flue gases, the direction of the currents of hot and cold air are reversed, when the other half becomes heated up by the hot exit gases, and the cold air is admitted to the already heated half of the regenerator. At this early date this was obviously a step forward, utilising the waste heat of the gases coming from the combustion flues of the ovens for the purpose of heating the air for the better combustion of the gas used for heating the ovens. The placing of the regenerators in the sole of the coking chamber, and so near to it, was not for the purpose of heating the bottom of the oven, but the shallowness of the chequer brickwork in this regenerator, owing to the small space available for the efficient heating of the air, and the other danger of the incoming cold air chilling the bottom of the coking chamber, with the further danger of leakage from this regenerator into the coking chamber, and *vice versa*, should make this method a very risky one, and one which it would be extremely difficult to manage or control.

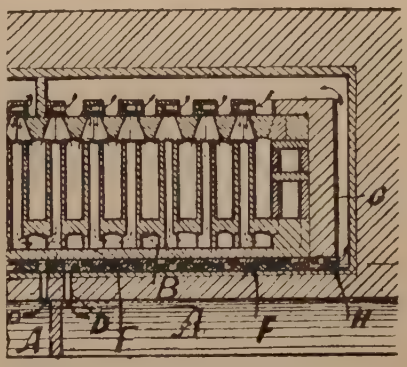


Fig. 113.—Vertical Section through Heating Flues of " Soldenhoff " Oven.

The modern system of regenerators as just described in connection with the Otto oven has been designed to overcome these risks, and difficulties arising from such close proximity to the coking chambers or combustion flues.

Kopper's Improvements in Coke Ovens.—As pointed out in a previous part of this chapter, in describing the class of ovens constructed with vertical heating flues, there is a great difficulty experienced in directing the flow of gas and air, and the products of combustion therefrom, so as to insure a uniform temperature, essential to the perfect carbonisation of coal and the formation of the best coke.

This matter was taken up seriously by Heinrich Kopper, who obtained several patents in Great Britain and other countries for his inventions connected with the regulation of the gases and with a more complete control over the practical working of this class of coke oven. Kopper made no great fundamental invention, but simply applied to existing methods certain improvements in the means of regulating the draughts, and the admission of gas and air to the combustion flues of coke ovens designated as the vertical flue type, and generally with regenerators.

His first improvement, B.P. 9822, A.D. 1901, relates to a construction of gas-fired coke ovens of the Coppée type, regulating the admission of air and gas to the vertical flues, and consists of a series of fireclay blocks, *a*, fig. 114, covering the heating flues, *h*, fig. 115. These blocks are provided with apertures

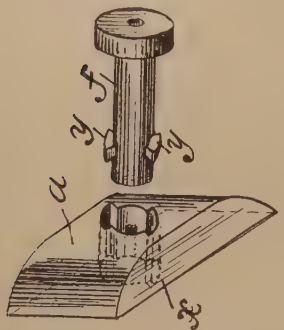


Fig. 114.—Kopper's Patent Stopper for Coke Oven Flues.

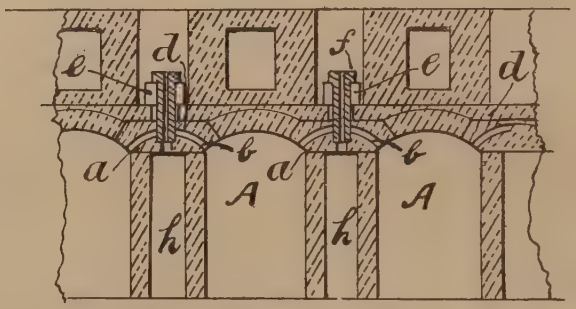


Fig. 115.—Vertical Section through Flues, showing Position of Patent Stopper (Kopper).

in the centre of them, which communicate with the ovens, A, A, by means of the spaces, *b*, constructed between the roof and the walls of the ovens at the springing of the arch. The spaces thus formed are covered with blocks, *d*, *d*, fig. 115, having apertures in them for the purpose of the insertion of removable air tubes, *f*, upon which are formed lateral snugs, *y*, fig. 114.

When the air tubes are placed so that the snugs rest over the lateral parts of the openings in the blocks, *a*, no gas can enter into the flues, *h*, from the ovens A, A, but when they are turned round and lowered, so that the snugs rest on the projections *x*, formed on the interior of these openings, the gas has free passage to the flues. The air supply enters by means of the air tubes *f*, already referred to, and when these tubes are removed and solid stoppers inserted the air supply is cut off.

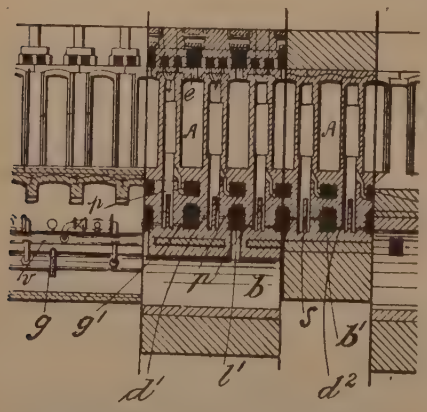


Fig. 116.—Cross-Section of "Kopper's" Coke Oven.

Kopper's next improvement, (?) B.P. 10,336, A.D. 1901, is designed for the use of either cold or hot air, and spent gases such as "chimney smoke," as a diluent mixture for the air for combustion, and by this means he attempts to regulate the temperature of the heating flues. He proposes a batch of by-product recovery coke ovens, represented in figs. 116 and 117. Fig. 116 represents four partial sections through the oven along planes at right angles to the axis of the ovens. Beneath each alternate oven, A, are gas passages g^1, and beneath all the ovens are air passages *b*; the passages, g^1, *b*, communicate with the heating flues by the apertures d^1 and d^2. When the oven is worked by means of cold air for combustion, the cold air and gas are supplied to the passage, g^1,

by means of the pipes v, g, and their branch pipes, m and n, fig. 117. These latter are provided with regulating valves, and connected by T-shaped pipes q. Cold air is supplied to the passages, l^1, through adjustable passages x; when

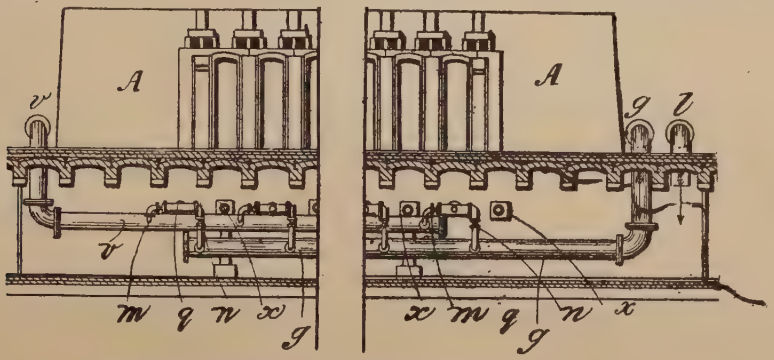


Fig. 117.—Longitudinal Sections of " Kopper's " Oven.

the ovens are worked with hot air for combustion, the conduit, l, fig. 118, which contains the hot air, is connected with the air-distributing passage l^1, fig. 116; this conduit, l, may be connected with a set of regenerators, which are separate and " entirely independent of the construction of the ovens." When, however, hot air is employed, a neutral gas, such as " chimney smoke," is supplied by means of the passages g^1, and the distributing passages l^1 supply the hot air for combustion. It will be observed that Kopper proposes to mix the air and gas previous to their entrance into the vertical combustion flues; in fact, he makes use of a horizontal flue in the sole of the oven for the purpose of conveying the mixed gas and air to the vertical heating flues. No doubt he has overlooked the fact that when a combustible gas is mixed with air and introduced into a flue beneath a heated coke oven, this mixture will take fire and burn

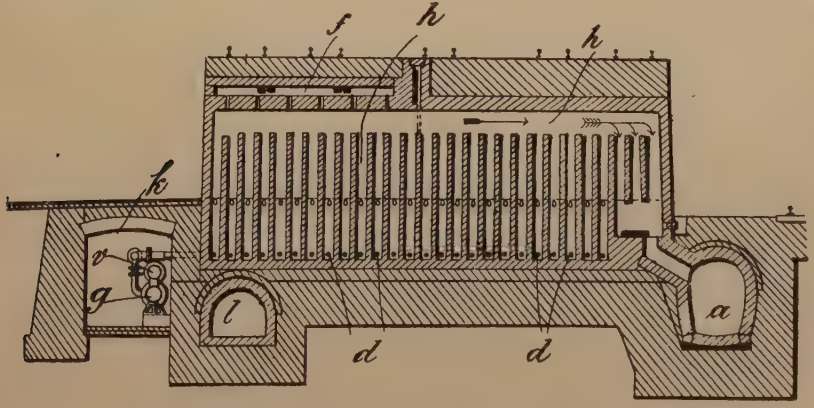


Fig. 118.—Vertical Heating Flues, " Kopper's " Oven.

right back to the point where the mixture takes place—viz., to the pieces mentioned and shown in fig. 117 at m, g, and n. When employing cold air this arrangement might work for a time, but would be extravagant on the gas

employed, as the chief heat would be in the horizontal flue, and the gas would, therefore, not fully heat the vertical flues. On the other hand, when using heated air mixed with neutral gases as a novel method of reducing the temperature of the mixture of heated air and gas, there would be difficulty in determining the quality of the neutral gas, which might be composed, not only of neutral nitrogen, but of a very large quantity of carbonic acid, which, not acting as a diluent like nitrogen, but as a positive non-combustible gas, would prevent the good gas from burning and promote its escape into the chimney half-burned. The mixing of gas and air previous to their ultimate destination for combustion appeared no doubt to this inventor as a mistake, as afterwards in the same year, 1901, he applied for another patent, B.P. 23,278, in which he states, "The regenerative coke ovens known at present suffer from the impossibility of obtaining a thoroughly uniform heating of the wall surfaces, so that repairs are continually necessary. In the regenerative coke ovens of known construction the gas is lighted in a channel below the flues, and then the burning gases are supplied to the heating flues. In a regenerative

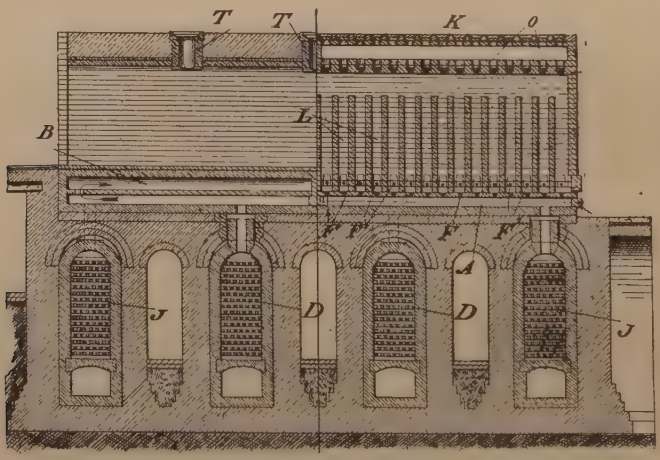


Fig. 119.—Longitudinal Section through Coking Chamber and Flues of "Kopper's" Oven.

coke oven improved according to the present invention gas and air are separately distributed to the heating flues before being lighted, so that the exact quantity of gas required for each flue can be easily regulated."

In this invention, which was intended to supersede the previous one, in which the gas was mixed with air previous to its entering the combustion flues, Kopper operates with a regenerative by-product coke oven of the horizontal type, and brings the air and gas to the point of ignition in separate channels, as shown at A, fig. 119, which are situated below the heating flues, and connected with the gas regenerator, J, when the oven is worked with "generated gas," or by a pipe lying outside the oven when using its own gas. The heating flues, L, communicate with the gas channel, A, by means of the nozzles F, one for each flue; the air channel is placed below the bottom of the ovens at B, and is connected with the air regenerator, D, on the one hand, and the heating flues, L, on the other; a connection with the air channel is made by means of the nozzle, F^1, on each flue. "*The separate distribution of gas and air*

to the heating flues, the forced conduction of the heating gases, and the removal of the ignition from the distribution channel into the heating flues are very important advantages in the new construction."

As the nozzles, F, are of very small diameter, they are liable to get choked with deposits of carbon or falling material from the flue; it is, therefore, necessary that they shall be accessible for inspection and cleaning; for this purpose above each flue there is an opening provided, O, through which the nozzle, F, is accessible, the opening being closed by means of a plate. This invention, it will be noted, describes a regenerative system, both for air and gas, and at this time the principle of heating coke ovens by gas and pre-heated air was coming into use, and superseding those in which the air was used cold for the combustion of the gas in the heating flues. No doubt economical high-temperature coking was the predominant object aimed at, and the fact of his latest method of burning the mixture of gas and heated air in the vertical heating flues, as described above, shows that experience of conducting this mixture first in the horizontal flue was a fatal mistake, endangering the horizontal flue by fluxing, due to the very high temperature that might be reached if heated air and gas were combined and ignited in the confined flue. The inventor is now upon firmer ground and a surer foundation in applying the regenerative system of using the surplus heat in heating the air for combustion of the gas, but applying this mixture to the lowest point in the combustion heating flue, with a direct upward direction to the flame. The pre-heating of both gas and air is quite unnecessary, as it may lead to dangerously high temperatures, higher than the brickwork of the ovens will stand.

Supplying the air pre-heated at one side of the heating flue, as at F^1, it would positively melt down the opposite wall, as the gas on ignition by the impetus of the air would impinge upon the wall opposite to the ingress of the heated air supply, causing it to be very much over-heated at this part. The universal supply of gas from a common channel into the several nozzles would also tend to give a redundancy to those nozzles nearest to the supply end, while those at a distance would have less, causing unequal heating of the flues.

In a later improvement, however, Kopper admits the air for combustion higher up in the vertical flue, so that ignition of the gas does not take place until the level of the sole of the oven is reached; by this later improvement this is to a certain extent modified, but the danger is not removed, as will be gathered from figs. 120, 121, 122. The air for combustion is introduced by an inclined channel, with the object of causing an upward current of flame with a swirling action, B.P. 17,283, A.D. 1903. The gas is introduced to the heating flues, *d*, *d*, from a common main, *a*, by nozzles *c*, *c*, and the pre-heated air is introduced through the openings, *e*, *e*, from the air channels *b*, *b*.

As pointed out in a previous part of this chapter when describing the difficulties occurring in the path of uniform heating, and also of the distribution of the heating flues in order to secure this desired uniformity, with the immunity from damage by overheating on the one hand, and underheating on the other, this inventor seems to have passed through this experience, and to have devised several methods and improvements progressively to overcome these difficulties, in the numerous patents for which he has applied, some of which are exceedingly complicated, and the working of which would necessitate highly skilled labour to effect all the adjustments necessary to get the required uniform temperature. Great ingenuity, however, is displayed in some of the arrangements, and they are given here, and to a certain extent described and illustrated, for the purpose of showing the development of the horizontal coking oven, and the determined

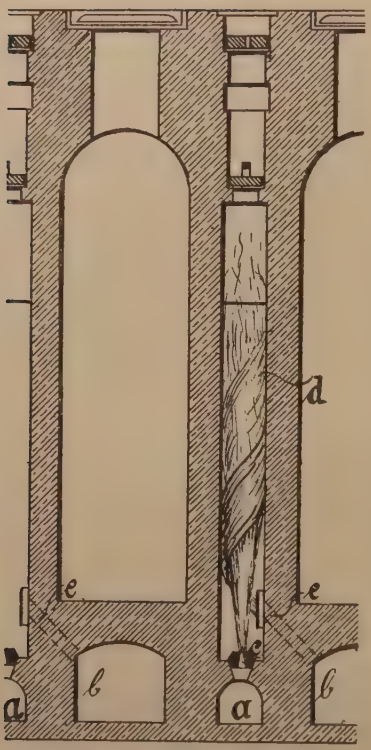


Fig. 120.—Cross-Section through Coking Chamber and Flues of "Kopper's" Oven.

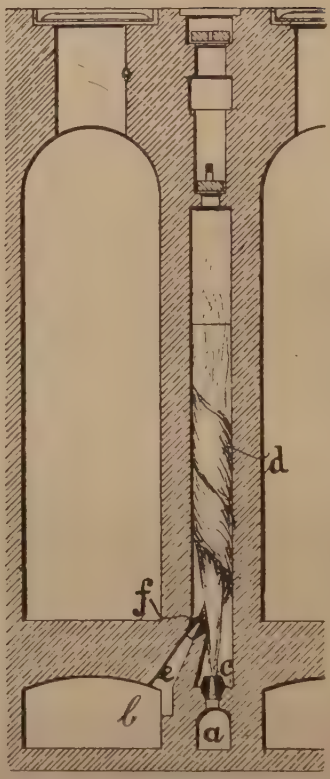


Fig. 121.—Cross-Section through Coking Chamber and Flues of "Kopper's" Oven.

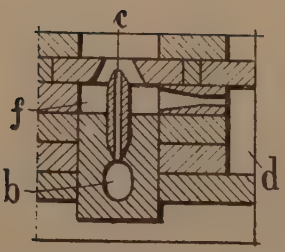


Fig. 122.—Section through Kopper's Gas Burner.

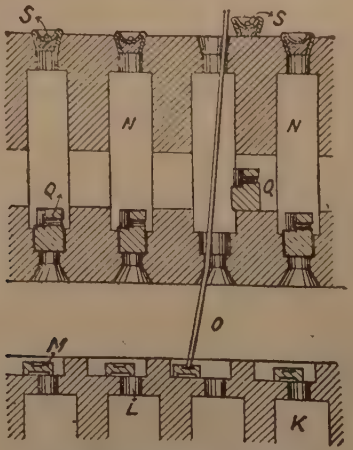


Fig. 123.—Section through Damper Valve, "Kopper's" Oven.

attempts to cope with its inherent difficulties with respect to heating, and at the same time to ensure stability and sound construction. He admits in his B.P. 18,262, A.D. 1904, " The great defect is want of uniformity of the heating effect, both within the separate heating flues and throughout an entire group of such flues arranged in series. As regards the separate flues, this want of uniformity manifested itself in the accumulation of heat at places where it was most prejudicial, so that thin or jet flames were formed which the refractory material was unable to withstand for any considerable time."

In his proposal Kopper hopes to overcome all the defects of heating by a novel method of introduction of air and gas, based upon a theoretical idea of the gas igniting and burning in the centre of a rising spiral current or column of heated air, as shown in figs. 120 and 121, a theory which does not always hold good in practice. He describes some further improvements relative to the constructional stability of these ovens, and to strengthen the walls, which were becoming gravely insecure and unsupported from the point of view of practical working, due to consequent wear and tear by unequal expansion and contraction of the different parts of the oven, and the fluxing effect of impinging flames when the theoretical flames of gas with their spiral air-sheaths were wont to burn adversely, and destroy in one part and inefficiently heat in another. He proposes to contract the upper part of the heating flues, in order to thicken the walls at this place, and just above this projection he places a " slide," to be operated from above, so as to act as a damper to increase or reduce the size of the heating flue, as shown in fig. 123, while he makes another improvement in the manner of burning the gas and in the introduction of the air for combustion. Fig. 122 shows the burner in detail; the gas is introduced by means of the channel *b*, and ascends through the small tube *c*; surrounding this tube is an annular space, through which the air for combustion is introduced by *f*, from the air channel *d*; by this means Kopper obtains the gas in the centre of a ring of air with an upward direction; fig. 124 shows the position of these details in the bottom of the heating flues. In this design he brings the air and gas in channels alongside each other in the base of the ovens, as at *b* and *d*, with branches to each separate jet or annular passage. In a construction of this kind a very serious difficulty often arises from the expansion and contraction of the brickwork, which is inevitable, and in this case would cause leakage of gas into the air channels, which would soon prove destructive to the brickwork of these parts and derange the working of the ovens.

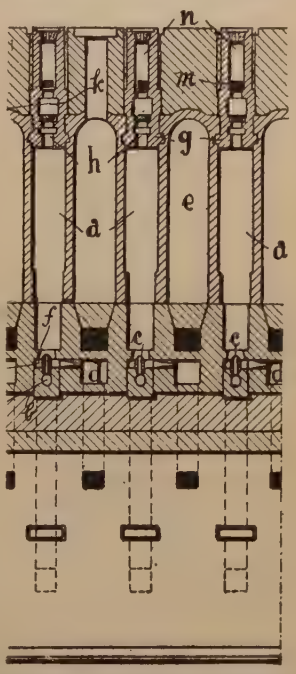


Fig. 124.—Cross-Section through Flues and Ovens of " Kopper's " Coke Oven.

Kopper's next important addition and alteration to his coking ovens was in his placing the regenerators under each individual oven, instead of the large collective one; this independent regenerative system was a step in the right direction, but its location was defective; such a system as the collective one, where the regenerators were placed so as to feed a series of ovens, was

unsatisfactory in practical working, because the plenum of pressure causing the draught in any one of the set of heating flues is never absolutely constant and equal to that maintaining in any of the other flues of the group; there are, in consequence, cutting draughts in certain parts, and shortages in others; these facts no doubt made themselves manifest in the practical working of the ovens with the common regenerator, and evidently led to the adoption of the independent regenerator for both air and gas. The improvements are detailed in B.P. 28,811, A.D. 1904, and B.P. 2145, A.D. 1908, and figs. 125 and 126 illustrate how these regenerators are placed under the ovens. Fig. 125 is a cross-section, and fig. 126 a longitudinal section through the regenerator and the coking chamber. These regenerators were divided into two portions lengthwise, with a tunnel, *b*, running between them, and over this a dividing wall *h*; the air for heating enters one side of the regenerator *b*, and passing out through the openings in the wall at the top, *e*, meets the gas issuing from the conduit *g*, and burns in the heating flue *f*; when both air and gas are to be pre-heated, the regenerators

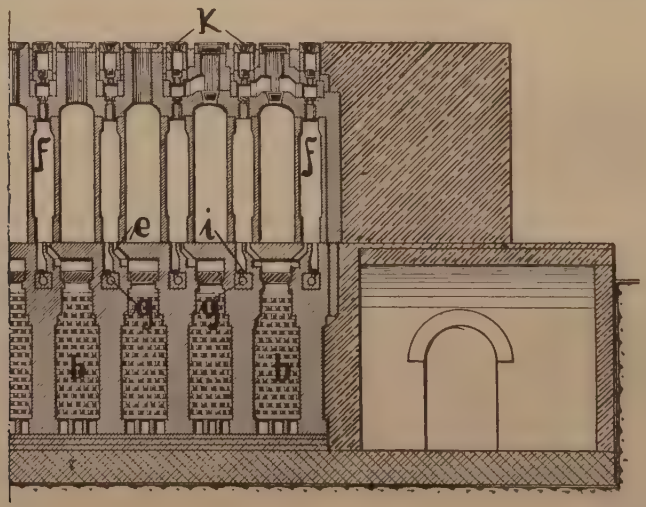


Fig. 125.—Cross-Section through Regenerator, "Kopper's" Oven.

are divided longitudinally by a partition; on one side the gas is pre-heated, on the other side the air is pre-heated.

In coke ovens of this type the great fault in design is in placing the regenerators at the lower part of the building of the ovens; the superstructure is thus resting upon walls that are part of the regenerators; this is no doubt a necessity in order to have as close proximity as possible to the source of heat of the exit gases, and also for the incoming heated air for combustion; but, on the other hand, the ovens themselves have in reality a greater claim for substantial substructure, in order to avoid the great wear and tear on such a construction; a great number of ovens have been constructed on this plan, and have been most successful in producing good coke; but, at the same time, in designing coke ovens of a permanent character, and where repairs are to be reduced to a minimum, the principle of keeping the foundations solid and secure is a good one. It will be gathered from figs. 125 and 126 that this has been a feature

in the design, as good solid walls are placed between each set of regenerators in these ovens.

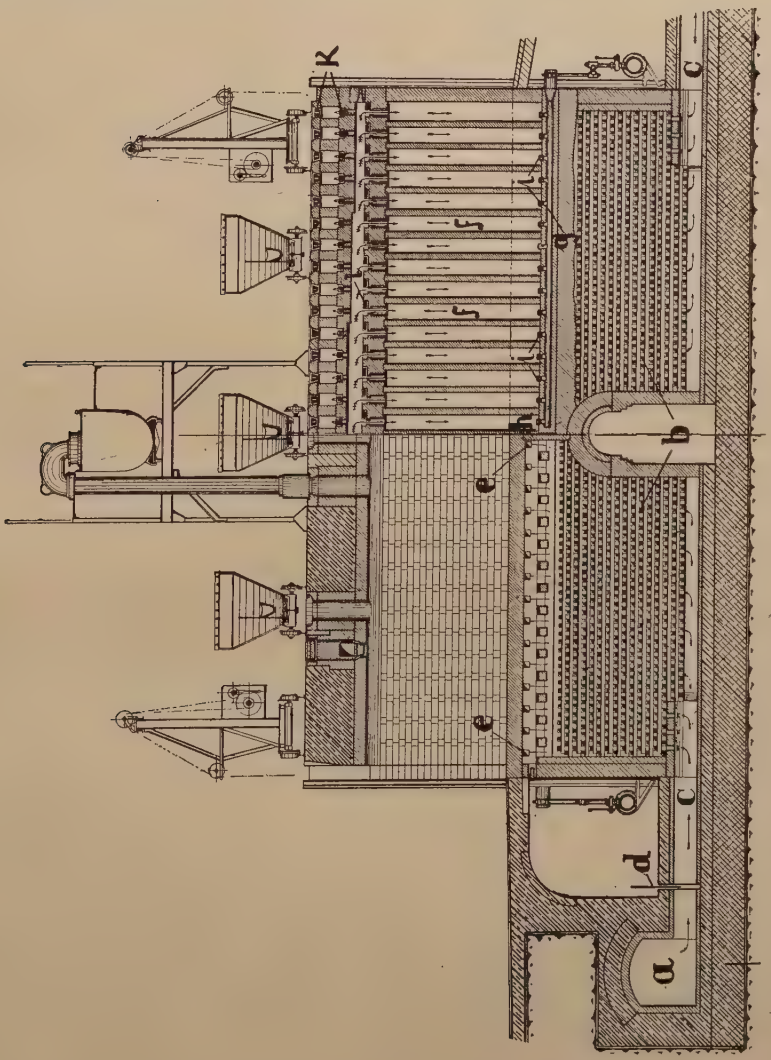


Fig. 126.—Longitudinal Section through Flues, Coking Chamber, and Regenerators, "Kopper's" Oven.

Horizontal By-Product Coking Ovens with Horizontal Heating Flues.—At the commencement of this chapter reference was made to a communication from abroad to J. Luis' patent agent in the year 1858 regarding a coking oven with horizontal flues, and further reference was made to that of Pernolet in 1862. Nothing further seems to have been done in this direction until 1864, when W. C. Stobart proposed to construct coke ovens with horizontal heating flues, superimposed. Fig. 127 shows a section through a range of coke ovens upon this principle; the design is for ovens in which the by-products are not taken from the gas, and in fact, judging from the width of the ovens, they are

more like Beehive ovens. The gas, however, after leaving the coking chamber, descends the back wall of the oven by means of the vertical flue B, and enters the horizontal flue at the bottom of the division wall, and passing along this

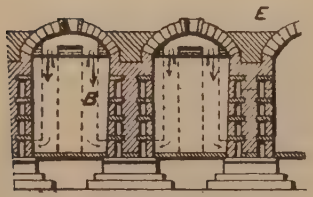


Fig. 127.—Cross-Section of "Stobart" Coke Oven.

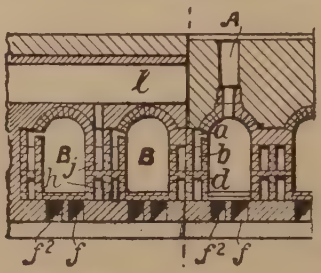


Fig. 128.—Cross-Section of "Gobiet" Coke Oven.

flue, returns by the next flue superimposed, and thus finds a zig-zag course up the division wall to the top, where the products of combustion enter the flue E. A similar arrangement was proposed by A. Gobiet in 1874, B.P. 2512, and is illustrated by fig. 128. The ovens are charged through the roof by openings,

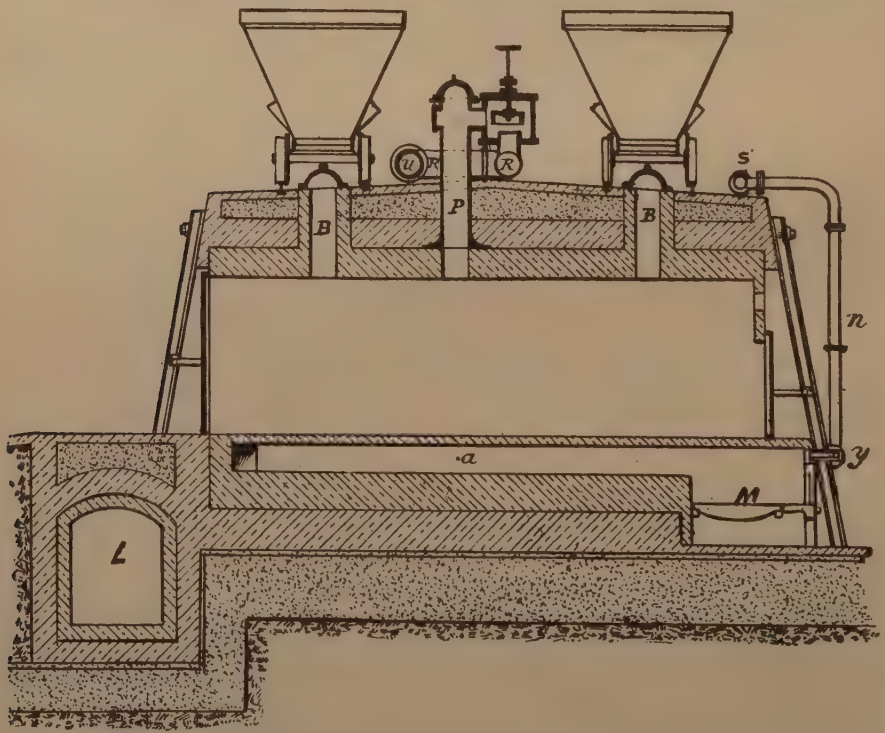


Fig. 129.—Longitudinal Section of "Simon-Carves" Coking Chamber.

A, into the coking chambers B; the evolved gas is passed through openings, *a*, into lateral flues *b*, which communicate by conduits at the end to the flues

d; from these lower horizontal flues the gases pass through apertures f^2 and *f*, following a circuitous course under the coking chamber, and then enter the flues on the opposite wall *h*, then through *j*, to the exit flue *l*, and to the chimney.

The first modern coking oven designed with horizontal flues was, however, the invention of M. F. Carves, of St. Etienne, France. H. Simon, of Manchester, in the year 1879, obtained a patent for this design as communicated to him from F. Carves, B.P, 2616. The coking ovens are arranged in a battery side by side, and heated by means of fireplaces M, from which the heated products of combustion pass along horizontal flues, *a*, fig. 129, beneath the ovens, and then to vertical flues *d*, *e*, thence to zig-zag horizontal flues, *f*, *g*, *h*, *i*, fig. 130, situated in the division walls between the coking ovens; these then deliver the products of combustion by the channel, *k*, to the flue L, and to the chimney. The gas produced in the coke oven is collected by the pipe P, fig. 130, and taken

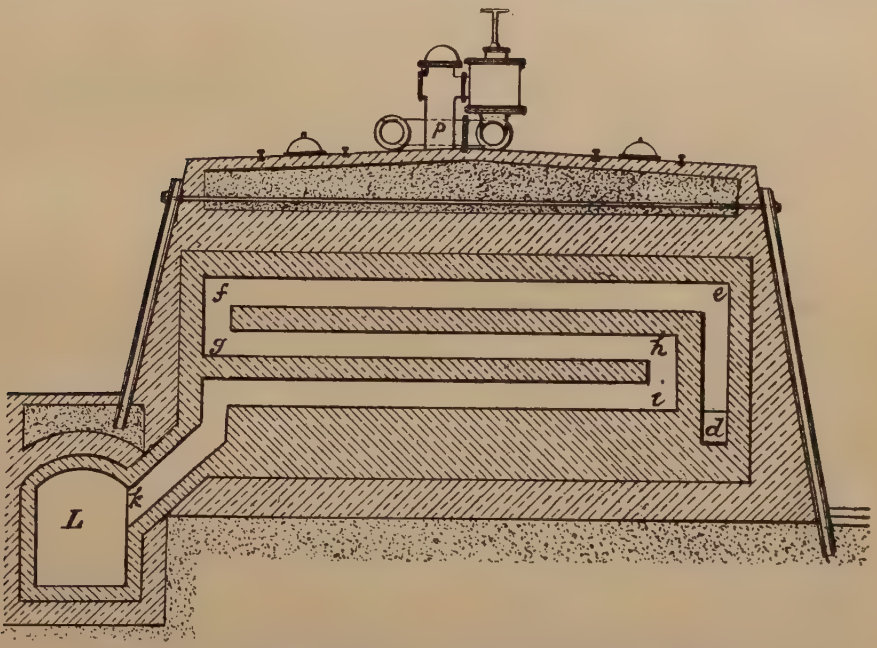


Fig. 130.—Longitudinal Section of "Simon-Carves" Heating Flues.

by the pipes R and U, fig. 131, to the by-product apparatus, where the by-products are extracted; the gas is then returned to the ovens by the pipe S^1, fig. 129, and the branches N and Y, to the furnace just above the fire grate, for combustion. In this early type of coke oven the idea of heating entirely with the gas produced from the carbonisation of the coal had not been appreciated; evidently the difficulty in starting or lighting-up the ovens may have had something to do with retaining the coal fire grate under the sole of the oven, but the details in other respects in many parts of this design are similar to those of the present day; and, as in the case already described of coking ovens with vertical flues, their gradual evolution by repeated improvements transformed them into the modern horizontal coking oven. It is proposed by the same method to trace the gradual evolution of the horizontal flue-heated oven by

the inventors who worked out the most important improvements. These will be represented practically by only two well-known types of ovens, viz., the Simon-Carves and the Semet-Solvay.

The step taken by Carves in 1883 was an improvement in the application

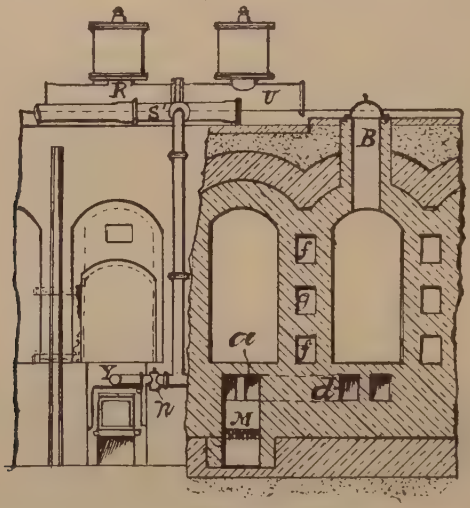


Fig. 131.—Cross-Section and Part Elevation of "Simon-Carves" Heating Flues.

of the regenerative system of heating the air for combustion of the gas, B.P. 554. The oven differs little from that just described; the fireplace under the sole of the oven is still retained, but no doubt with the addition of the pre-heated air it was soon found that the fire grate was quite superfluous. Figs.

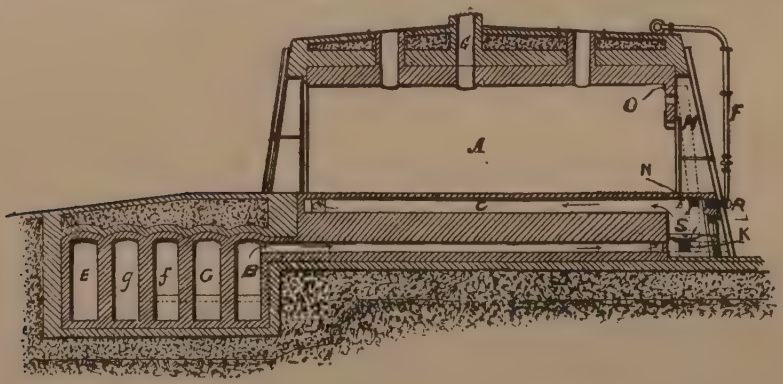


Fig. 132.—Longitudinal Section through Oven ("Simon-Carves").

132 and 133 show the additional arrangements made to effect these improvements. The coking chambers are the same and of narrow dimensions, with the fire grate S, below them and with the flue, C, passing under the floor of the coking chamber, fig. 132. This flue is carried up the wall, and then in a zig-zag direction

descends, as in the oven before described, but in this case the exit, instead of entering into the chimney flue direct, is carried into the flues *g* and *c*, fig. 133, which extend along the side of the whole range of ovens, each flue being closed at one end and in connection with the chimney at the other end. The branch flues from the ovens, C^2, fig. 133, communicate alternately with flues *g* and C; the gases in these flues, therefore, travel in opposite directions; an air

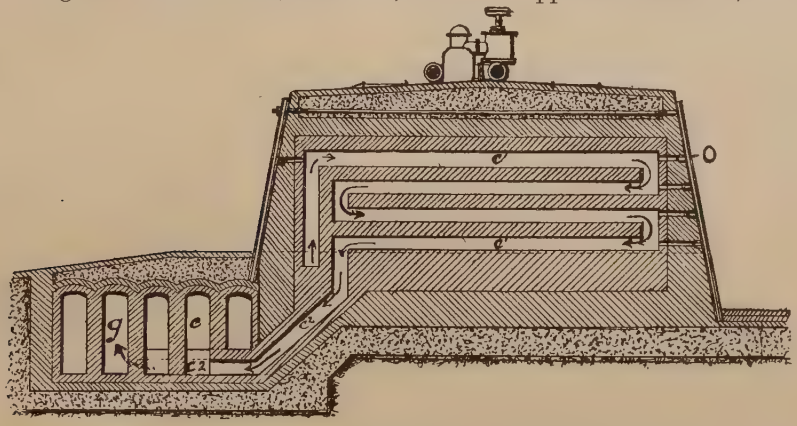


Fig. 133.—Longitudinal Section through Heating Flues and Recuperators, "Simon-Carves" Oven.

flue, E, fig. 132, is placed on the outside of the flue *g*; it then passes between the two flues *g* and C at *f*, and then turns along the inner side of flue C; from this flue, which is now B, branches are carried to each fireplace, the heated air entering through the openings K, fig. 132, and quite close to the opening for the admission of the gas nozzle R. By this arrangement the gas is ignited and burned along the flue C; the hot air flue is also carried up the front of the oven to the point O, and enters the top flue C^1, fig. 134, in order to complete the combustion of the gases before descending in their zig-zag course down the wall between the two adjacent coking chambers. The gas for combustion is brought from the by-product plant in pipes F, fig. 132, and is supplied above the fireplace, S, by means of the nozzle R. A modification of this plan is also arranged, whereby only one flue may be used to take all the exit gases, on each side of which an air flue is placed, so that the air to be heated passes in an opposite direction to the exit gases of combustion; or, when a reversing valve is used, the air flue may serve for the waste gas flue alternately by the well-known system with the half-hourly reversion; the waste heat can also be utilised for raising steam previous to the exit gases of combustion passing into the chimney. Although mention is made of a regenerator such as that used by Siemens, filled with bricks, it is a little difficult to understand in the absence of any details in the drawings how this can be arranged, or how a regenerator could possibly work successfully at such a distance from the source of heat, and the uneconomical waste of heat by absorption in the long communication flues. It also

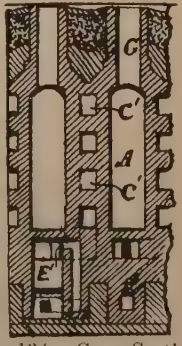


Fig. 134.—Cross-Section through Heating Flues and Recuperators. "Simon-Carves" Oven.

seems that the hottest part of the coking chamber was in the sole, as practically the whole of the gas would be burned in this flue. It is, therefore, by considering the method of "regeneration" of the air, that it was delivered at the gas nozzle at no great temperature, otherwise the roof and sides of the fire grate must have suffered from its effects, while the opposite end of the heating flue would be insufficiently heated, producing inequality of heating in the walls of the coking chamber, and it is most surprising that Carves did not attempt to remedy these defects earlier than the year 1901.

The modern types of ovens for the carbonisation of coal designed and constructed by Messrs. Simon-Carves, Ltd., of Manchetser, are of two kinds—viz., the waste-heat oven with horizontal flues, and the vertically-flued regenerative oven. The following is a description of these two ovens :—*

The Simon-Carves Waste-Heat Ovens.—These ovens are built on brickwork arches running longitudinally under the battery, the arch nearest the ram

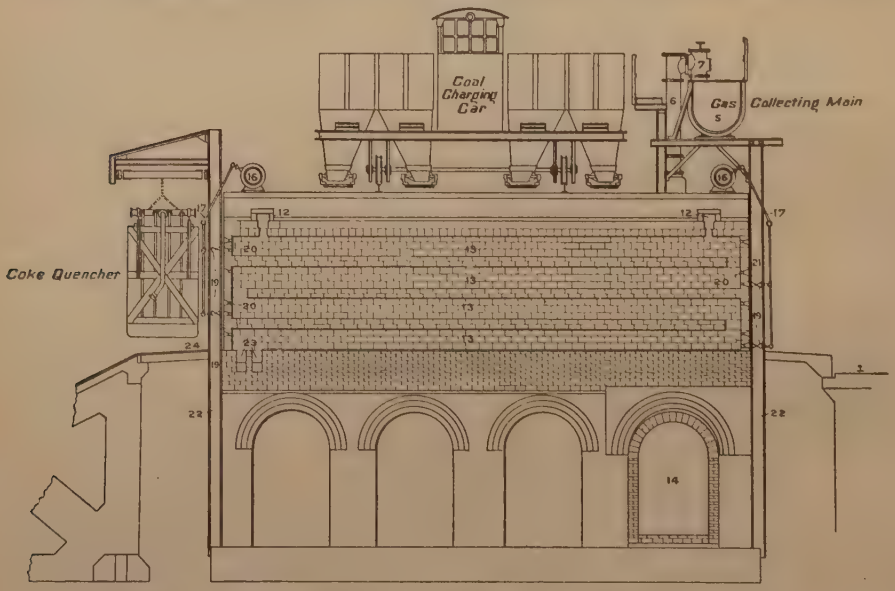


Fig. 135.—Horizontal Section through Flues, "Simon-Carves" Oven.

side of the oven being arranged to cover the flue collecting the waste gases from each oven, the design being made suitable to the conditions obtaining. The walls forming the sides of the chambers are provided with a double set of four horizontal flues, 13, figs. 135, 136, and 137, and with a solid central pillar to carry the weight of the superstructure. The flues run from end to end on each side of the pillar, and the gas for heating the same, together with the air requisite for the combustion of the gas, is admitted at four different points, each section of the flue being supplied independently, and the combustion gases after heating the walls pass along the flue 24 under the sole of the ovens to the waste-gas flue, 14, fig. 136. The ovens are constructed of materials suited to the various conditions obtaining during their operation, and provision is made in the design to accommodate the expansion likely to occur at different points.

* Private communication from Messrs. Simon-Carves, Ltd.

The outside walls are supported by heavy steel buskstays, 22, fig. 137, with positive connections, and the latter may be adjusted to meet the various conditions encountered by the expansion in heating up the ovens.

The diagrams shown in figs. 135, 136, 137 are various sections through

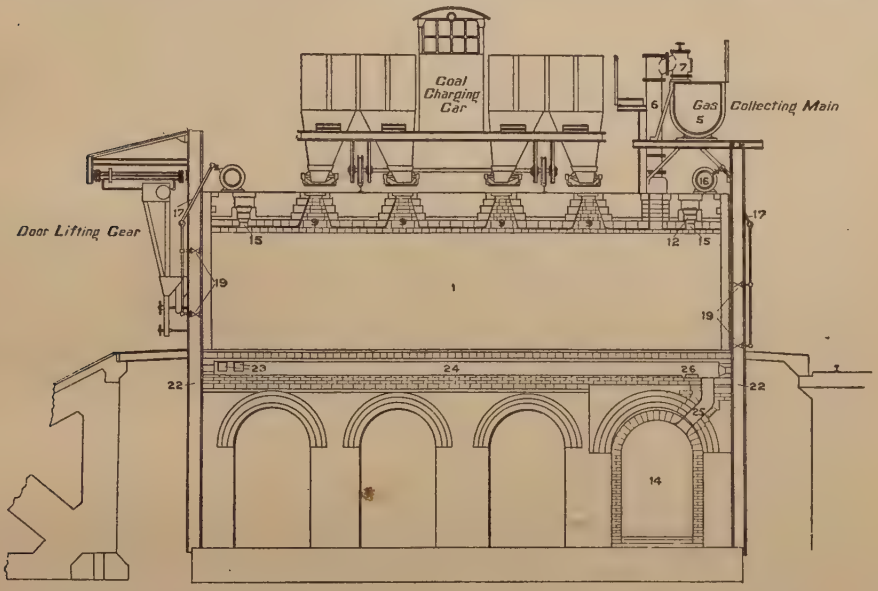


Fig. 136.—Longitudinal Section through Coking Chamber, " Simon-Carves " Oven.

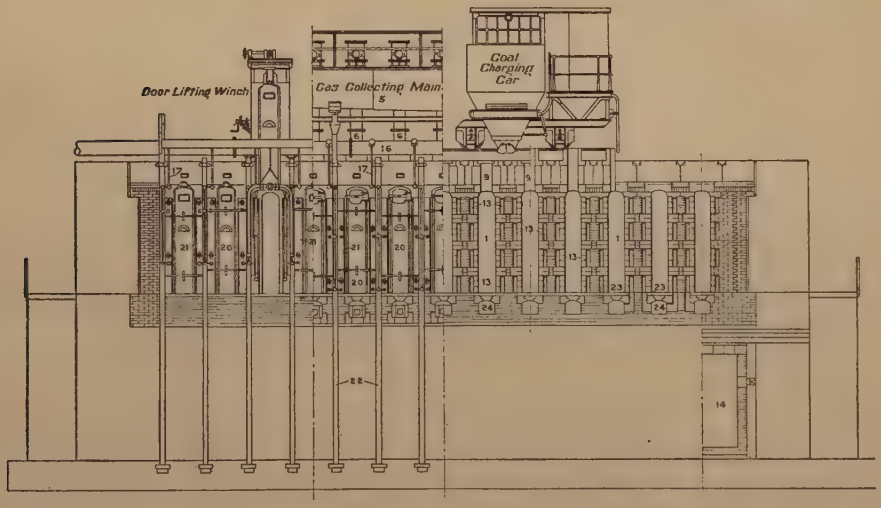


Fig. 137.—Cross-Section and Part Elevation of Coking Chamber, " Simon-Carves " Oven.

this oven. Fig. 136 is a longitudinal section through the coking chamber. Fig. 135 is a longitudinal section through the heating flues, and fig. 145 is part elevation and part cross-section through the heating flues and coking chambers.

The gas from the ovens after having been through the by-product plant for the extraction of the tar, ammonia, etc., is returned to the ovens for heating purposes by means of the main pipe, 16, which passes down each side of the battery of ovens; a separate supply is conducted to each oven by branch pipes, 17. The off-takes to the flues are proportioned to deliver the requisite amount of gas required at a given pressure: this is under control by means of the cocks, 19, on each off-take pipe, by which adjustments may be made. The gas pressure is regulated by a station governor on the main supply pipe feeding the distributing mains, 16.

The air required for combustion of the gas is admitted through air regulators, the primary air being admitted by a valve on the gas mounting, and the secondary air is governed by the regulator, 21. The combustion of the gas takes place in the flues, 13, and passes along them from the top downwards, after which it enters the two openings, 23, fig. 137, into the flue running under the sole of the coking chamber, 24; after passing along the flue, the products of combustion find their way down the ducts, 25, fig. 136, into the waste gas flue, 14, the draught on each oven being regulated by the damper block, 26.

Spy holes are provided at the end of each oven, for the easy examination of the horizontal flues: the outsides of the pillars are protected by cast-iron "armour plates," 21, completely covering same, by which it is stated that protection is given to the oven walls against any fluctuation or variation of temperature.

When the ovens are started, the openings in the roof, 15, fig. 136, are for the purpose of starting up the battery by means of the gas and products of combustion, which, instead of going into the ascension pipe, go through these openings direct into the top flue, 13, through opening 12. The lighting up is done by means of a fire placed in each end of each coking chamber against the door, and the hot products of combustion are led through the openings, 15, into the channels, 12, fig. 136, into the flues in the oven walls, escaping into the waste-heat flue through the sole flue. This process of heating up goes on until the temperature is sufficiently high for the purpose of distilling the coal, so that the ovens may then work by means of gas instead of fire; the openings in the top of the ovens are closed by dampers inserted from the top of the battery of ovens. The ovens are then charged with coal, which is effected by means of the four openings in the roof, 9, figs. 136 and 137, the coal being conveyed and fed into these openings from trucks electrically driven, or by other means, and the final distribution of the coal in the oven is completed by means of a mechanical levelling machine. The oven doors are removed and replaced by a mechanical device, the coke being discharged on completion of carbonisation by an electrically-operated ram, the latter being suited in each case to the system of handling and quenching which may be adopted. The gas given off during the carbonisation process ascends by the ascension pipe to the hydraulic main, 5, fig. 135; a disc type of isolating valve, 7, is provided for each oven. The gas is led from the collecting main, 5, to the by-product plant, after which it is returned to the ovens by the main, 16, for the purpose of heating the flues. The distribution of the gas to the flues is shown by the off-takes from the pipe, 17.

The Vertical-Flued Regenerative Oven is the second type of oven. This type is built in a battery on four brickwork arches running longitudinally under the battery, the external arches on either side of the battery forming the regenerators. Each regenerator is connected by means of conduits with separate longitudinal flues running under the central arches, which serve to carry off the waste products of combustion from the regenerators to the chimney stack. Fig. 138

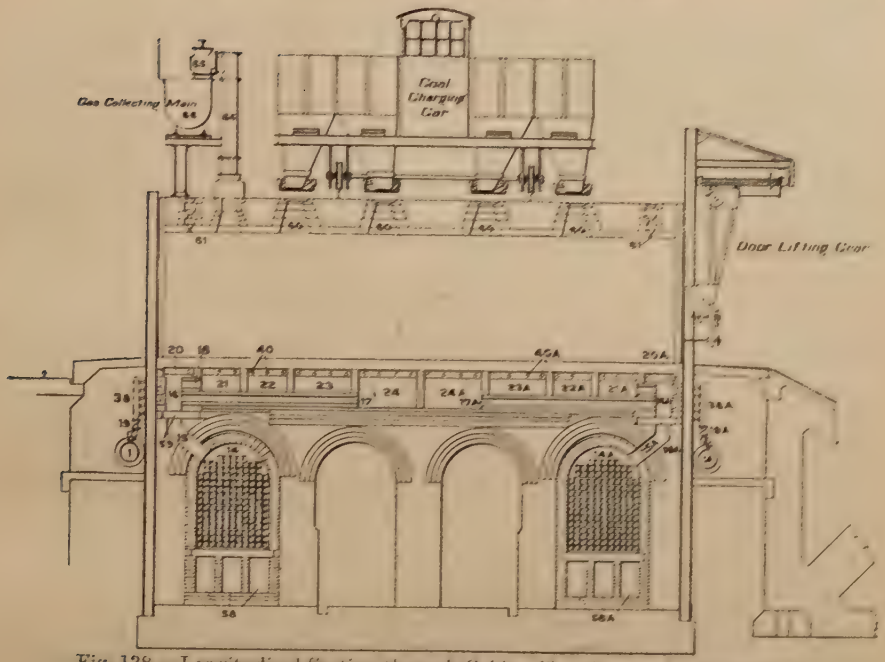


Fig. 138.—Longitudinal Section through Coking Chambers and Regenerators, "Simon-Carves" Oven.

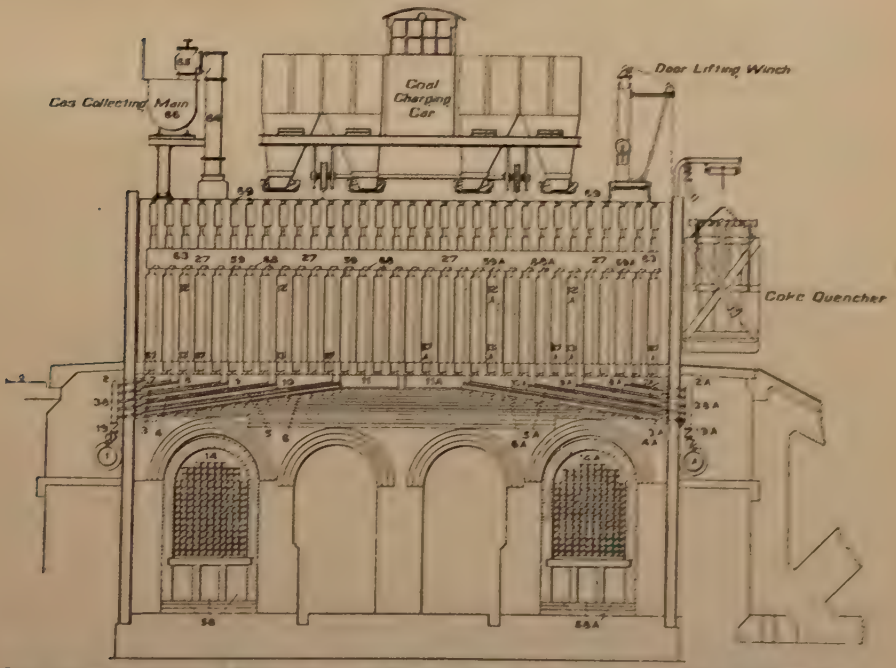


Fig. 139.—Longitudinal Section through Heating Flues, "Simon-Carves" Regenerative Oven.

shows a longitudinal section through the coking chamber; fig. 139 is a longitudinal section through the heating flues and across the regenerators.

These ovens are so constructed that by means of the vertical partitions in the regenerators each oven with its own particular system of heating flues is served by its own section of the regenerator; each section of the regenerator is provided with a separate conduit to the waste-heat flue, and also with a distinct and separate conduit for the admission of air. The arrangement provides for the separate control of both chimney draught and air supply for combustion of the gas. The central arches running under the whole battery of ovens serve for the admission of the external air to the regenerators, and these, traversing the sides of the regenerators, and running under the soles of the ovens, absorb the heat radiated from the walls, and while thus pre-heating the air for the regenerators, it keeps the foundations of the central pier wall comparatively cool. Openings are provided at intervals throughout the length of these arches communicating with the air conduits to the regenerators; these are fitted with mouthpieces and flap valves, which, when open, permit of the admission or otherwise of air to the regenerators.

The walls of the ovens are constructed with vertical flues, 32 in number; the products of combustion from these flues find their exit into a common horizontal flue, 27, fig. 139.

The axis of the battery of ovens divides the heating walls, flues, and regenerators, etc., into two symmetrical portions. Each combustion chamber is connected with the external gas pipes by means of a firebrick gas conduit, 7, 8, 9, 10, 11, and 7*a*, 8*a*, 9*a*, 10*a*, 11*a*, so that each set of combustion chambers is provided with a separate supply of heating gas, under control and adjustment. An opening is provided in the solid brickwork of the oven tops, 69, above each vertical flue, for the purpose of inspection, the aperture being closed with a cast-iron plug. At the base of each vertical flue is an orifice, 40, 40*a*, and 20 and 20*a*, fig. 138, leading to horizontal flues running under the sole of the oven, which in turn are connected by a conduit, provided with dampers, running to the regenerators. There are four of these horizontal flues, fig. 140, two for each half of the oven, and each flue is connected to eight adjacent combustion chambers; the conduits serve the purpose of conveying hot air to the combustion chambers, and alternately for the conveying of the products of combustion to and from the vertical flues and the regenerators. Dampers are provided at the end of the waste-heat flue nearest the chimney stack, and connected by cables with a winch, as also are flap valves, and gas supply cocks, for the heating gases, and the reversal of the draught, which is effected every half-hour, and the supply of gas and air for each side of the ovens; these operations are accomplished with a single operation of the winch.

The gas from the by-product plant is returned to the ovens by the gas main pipes, 1 and 1*a*, fig. 139, running on each side of the bench of ovens; a separate supply of gas is directed from these mains by branch pipes to each set of flues in the oven wall by the connection, 38 and 38*a*, through cock, 19 and 19*a*, leading to the firebrick conduits, which take the gas supply to the combustion chambers at 7, 8, 9, 10, 11, etc., for each adjacent pair of vertical flues for one-half of the oven walls.

The air after traversing the chequer brickwork in the regenerator, 14, passes by way of the conduit, 15, into the sole flues, 16, and from there is led through the nostrils, entering the combustion chambers, figs. 139 and 140, and meets there with the gas, which burns up the vertical flues, emerging into the horizontal flue, 27. These mouths of the vertical flues in the horizontal

flue, 27, are provided with covers, 68, for the regulation of the draught in each individual vertical flue. The products of combustion then descend from the flue, 27, to the vertical flues, fig. 139, forming the other half of the wall; then

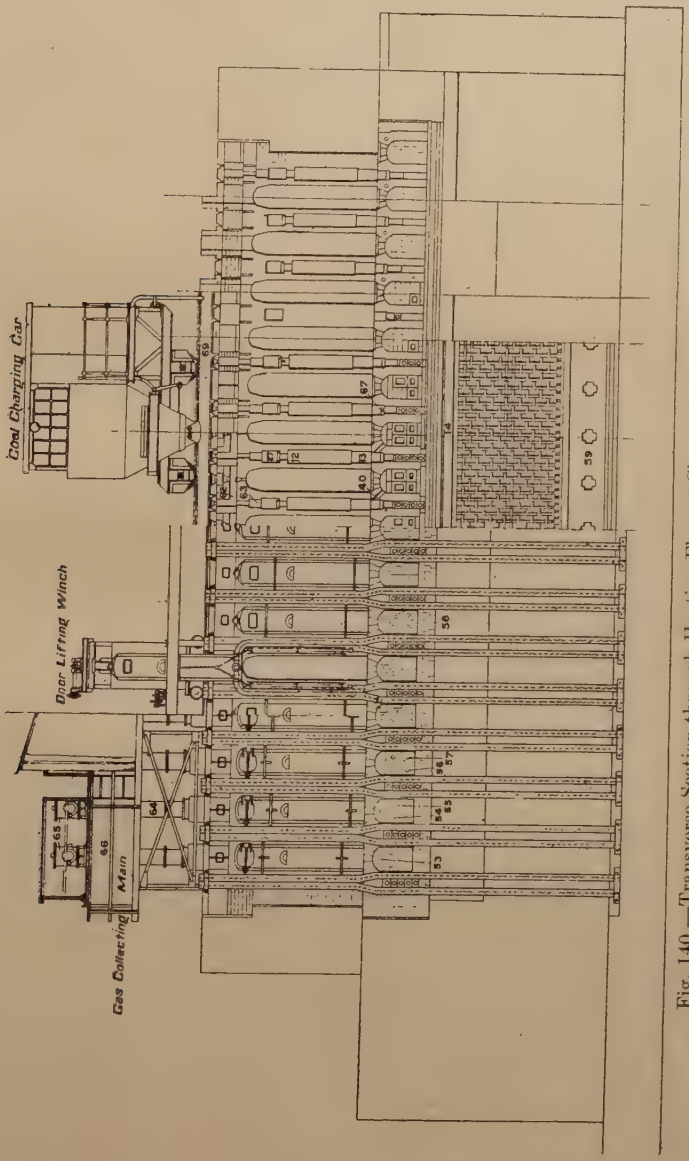


Fig. 140.—Transverse Section through Heating Flues, "Simon-Carves" Regenerative Oven.

by the way of the nostrils and sole flues and conduit, 15*a*, into the regenerator, 14*a*, and thence into the waste-heat flue and to the chimney stack.

After each half-hour the flow of gas, air, and the waste products of combustion is reversed. Each half of the oven walls is thus symmetrical; on the

reversal the gas is admitted on the other side of the oven, and the flow of gas, air, and products of combustion then reversed. The downtake vertical flues now become the uptake flues and *vice versa*. In the regenerator and sole flues, through which the waste products passed in one direction in the previous interval, the air for the combustion of the gas passes in the other direction and *vice versa*.

The underfed vertical-flued regenerative type of the latest design is shown in fig. 141 ; it is designed for large-capacity, quick-coking ovens, and constructed with vertical flues having parallel regenerators ; a sectional plan, A, A, B, B and C, C, is given at the lower portion of fig. 141, and the vertical section through the coking chamber, the regenerator chamber being on the right, and the heating flues and gas distribution flues on the left ; there are also three vertical cross-sections through the ovens, F, F, G, G and H, H, the latter being a section through the large flue to the chimney in the lower portion and an outside elevation of the front of the ovens on the upper portion. These ovens are provided with individual parallel regenerators, which are placed immediately under the oven chamber. In the oven pillar walls there are 28 vertical flues, each flue being provided with its own gas tuyère ; these tuyères are vertical, and pass through the side walls of the regenerators. The air supply is admitted to the sole flue of each regenerator by a separate air valve communicating with the basement. This also serves to ventilate the basement and keep it at a reasonable temperature. The method of heating this type of construction is as follows :— Each regenerator is either communicating with air-flue or chimney, fig. 141 ; while the regenerators, A, are heating up the air, the regenerators, C, are taking the waste gas products.

Air enters at the air valve, D, from the basement and passes into the regenerator sole flue F. It is then pre-heated in the chequer brickwork regenerator A, and passes through the air ports, G, into the vertical pillar flues. The air ports, as indicated on the sectional plan, fig. 141, are arranged in alternate groups of seven jets each. The right-hand ports connect to regenerator A, and the left-hand ports to the regenerator C.

The pre-heated air and the combustion gas take the following course :— In the first group air from regenerator, A, passes through the right-hand ports, G, up flues 1 to 7 inclusive, along the horizontal flue K, then down the vertical flues 8 to 14 inclusive, then through the second group (left-hand) ports and into regenerator C. The above is the course of the combustion gases from the air supplied by the first quarter of the regenerator. The air from the third quarter of the regenerator, A, passes through the third group (right hand) of ports, and up vertical flues, 15 to 21, in pillar H, then along horizontal flue, K, down vertical flues 22 to 28, and through the fourth group (left hand) of ports into the regenerator C. So far only the first and third quarters of the regenerator, A, have been dealt with as supplying air to the pillar H ; the second and third quarters supply air in an exactly similar way to pillar J, except that the flow in the horizontal flue of pillar, J, is in the opposite sense to that of pillar H. It will thus be seen that the reversal of the heating gases, instead of taking place over a complete half of the oven, takes place over a quarter of the oven, and considering the coal charge in any one particular oven, the gas will be burning as follows :—

First quarter—right-hand pillar.
Second quarter—left-hand pillar.
Third quarter—right-hand pillar.
Fourth quarter—left-hand pillar.

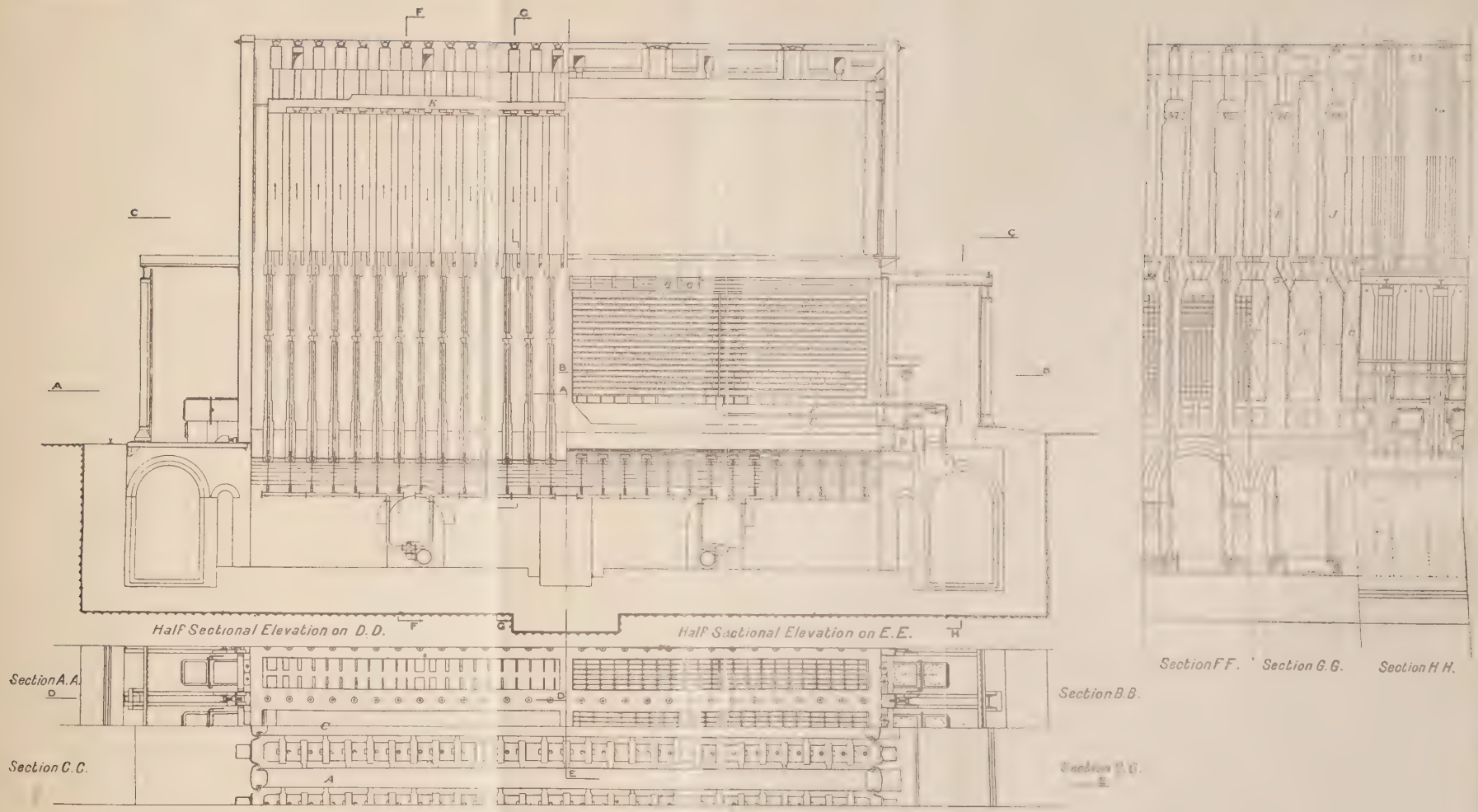


Fig. 141.—Regenerative Coke Oven, Latest Type, "Simon-Carves."

In this design both the main waste gas flues running alongside the battery are always on the chimney.

There are two gas supply mains and four groups of seven gas burners each; each group is provided with a reversing cock. This system has the advantage that different pressures can be employed in the two gas mains, and two sizes of gas nozzles can be used, thus giving four different rates of gas combustion along the length of the oven, and each regenerator can be divided into four sections, each section with separately controlled air supply. The heating of the oven wall can be varied throughout its length to compensate for the variation of the thickness of coal charge in tapered ovens.

The method of reversing by quarter pillars also reduces the height of the horizontal flue K, which is the weakest portion of the oven wall, and at the same time permits of a greater area of the oven wall being under the influence of radiant heat.

Semet-Solvay Coke Ovens.—The horizontal coking oven as first described, of the Simon-Carves type, is almost similar to that designed by the Semet-Solvay Company, but there are essential characteristic details in the latter that possess distinctive features.

This oven was introduced about the year 1880, a patent being granted to Louis Semet and Ernest Solvay of Brussels, B.P. 4733. They propose to construct their oven either with vertical or horizontal heating flues, the construction of these heating flues being the most important feature in this invention. They are preferably made in sections as tubes, for the purpose of curtailing the numerous joints that are necessary when constructed of brick. These tubes are shown in figs. 142, 143, 144, 145, and are so formed that the sides may be made comparatively thin, so that the heat may be made to penetrate more rapidly than when the necessary thicker walls of brickwork are used.

Figs. 146 and 147 show the general arrangement of a horizontal coking oven constructed for this method with vertical heating flues. It will be observed that the length of the oven is divided into three heating divisions, each division forming a separate heating zone, of five vertical flues, the flame pursuing an upright and downward zig-zag course, fig. 146. The heat proceeds from the fireplace, *f*, under the sole of the oven by means of the flue *y*, then ascends at the end of the oven by the vertical flues *h*, *h*, then returns over the roof of the flues by the channel L. Ports provided with dampers are situated over the three entrances to the three divisions, the heat proceeding, as indicated by the arrows, in a zig-zag course. The ovens, A, are fed with coal through the apertures in the roof *x*, the gas from the carbonisation of the coal ascends through the tube, *a*, into the pipes to the by-product plant, and the stripped gas is returned to the oven by the tubes *c*, with branches; the gas enters the fireplace through the tuyère *e*, along with heated air for combustion, which is heated in its passage through the conduits, *t*, *t*, in the foundations, from which it is led to the tuyère, *e*, by the pipes *d*, *d*. The products of combustion after passing throughout the flues pass into the conduit, *q*, to the chimney.

Figs. 146 and 147 show respectively sections through this oven with vertical heating flues. Fig. 146 is a section on the right hand through the heating flues on line D C, fig. 147, and on the left hand on the line A B, fig. 147, through the oven with the fireplace beneath. Fig. 147 is partly a cross-section and partly an elevation of the front of the ovens, showing the iron doors. This

invention provided for the adoption of two methods of heating the coking chambers; the first method by means of vertical heating flues, described above, and the second method by horizontal flues superimposed. The drawings attached to the original specification show three flues, horizontal

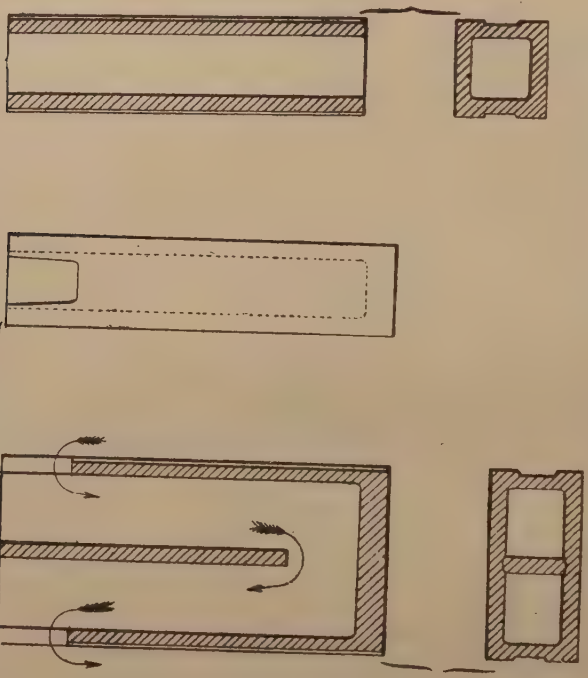


Fig. 144.
Sections through Patent Tubes for Heating Flues of "Semet-Solvay" Oven.

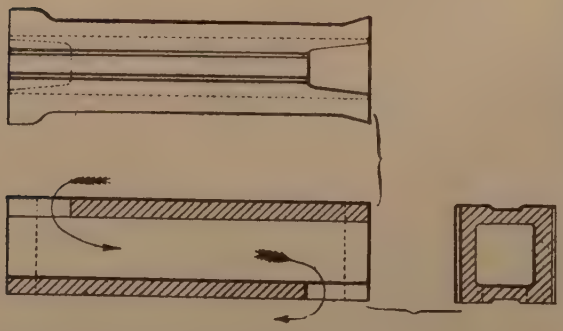


Fig. 143.—Sections through Patent Tubes for Heating Flues of "Semet-Solvay" Oven.

and superimposed; these were heated in the same manner as that described above for the vertical flues, that is, by means of a fire grate and also by means of gas brought back from the by-product plant to the grate and burned as shown in fig. 146. A section through these heating flues

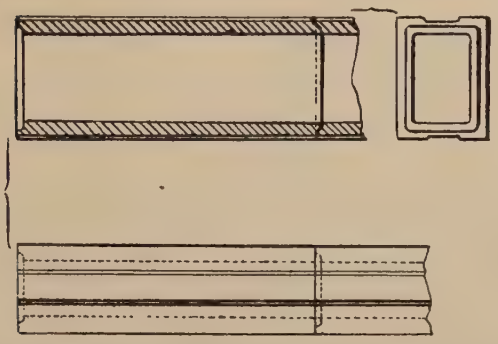


Fig. 145.—Sections through Patent Tubes for Heating Flues of " Semet-Solvay " Oven.

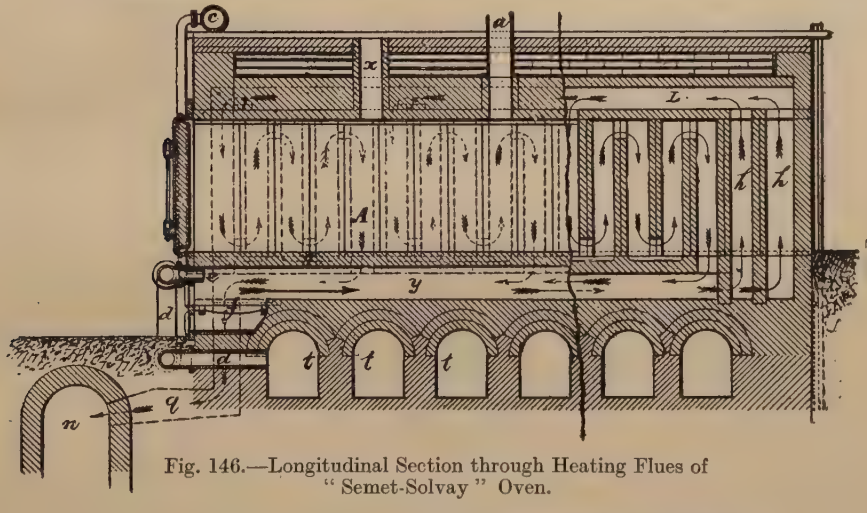


Fig. 146.—Longitudinal Section through Heating Flues of " Semet-Solvay " Oven.

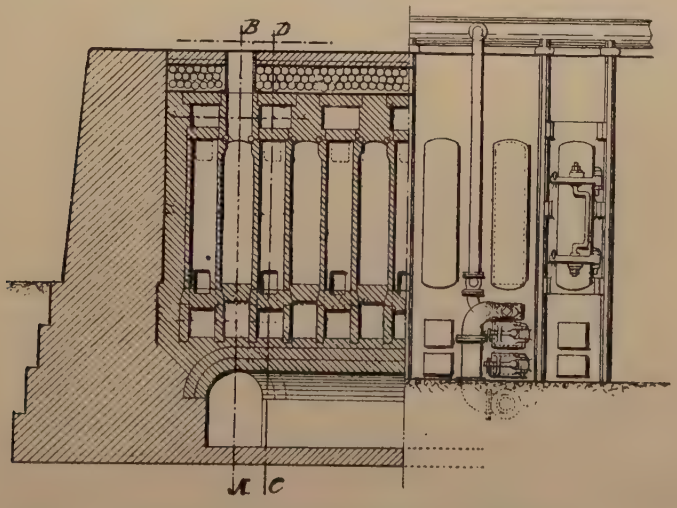


Fig. 147.—Cross-Section through Heating Flues "Semet-Solvay" Oven.

is shown in fig. 148, and a cross-section through the heating flues and coking chamber is shown in fig. 149.

It is easy from what has already been stated in a former part of this chapter, criticising the methods adopted by various inventors to heat horizontal ovens by means of vertical flues, to realise the difficulties in the way of these two latter inventors, in respect of even being able to heat their oven economically

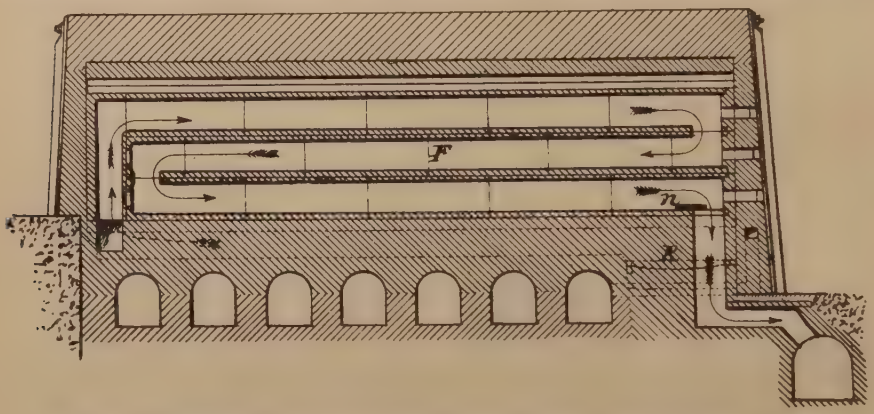


Fig. 148.—Longitudinal Section through Heating Flues of "Semet-Solvay" Oven.

and efficiently by the means set out in their proposals as described above. The fact of their having abandoned the vertical flue proposition, and confining their attention to the horizontal flue construction, shows that they took the right course to obtain good results without further trouble. The design of their flues, made up as they are of fireclay blocks, as shown in figs. 142, 143, 144, and 145, built independently of the constructional division walls of the coking chambers, is the chief feature of their success. These horizontal flues are made of substantial proportions, and are constructed with joints with rebated faces, so that when built up they may retain their place and shape under the heat they have to stand. The vertical joints are rebated, so that a firm hold is made on each end of the tubes as they are placed together end to end, while the top and bottom longitudinal sides are sunk to receive the jointing material, which fixes them in their place; the ends where the horizontal flues turn and are reversed is made in one block, with the double flue in it, as in fig. 143; this finishes the end next to the outside oven walls, and also serves the purpose of fixing both top and bottom flues in their respective positions. The principle of constructing these flues separate from the oven walls is a good one, and allows of repairs, even to the extraction of all the flues and the insertion of new ones without interfering with the walls or constructional parts of the oven; in fact, it makes each compartment, both for heating and repairs, absolutely independent. There is no doubt the first cost of con-

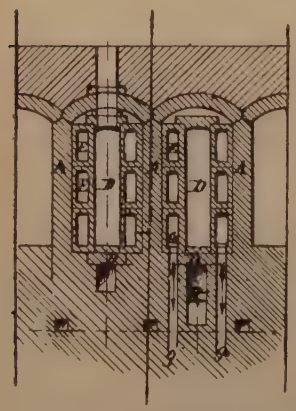


Fig. 149.—Cross-Section through Heating Flues of "Semet-Solvay" Oven.

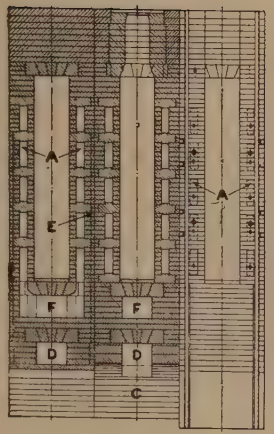


Fig. 150.—Cross-Section through Horizontal Heating Flues. "Semet-Solvay" Oven.

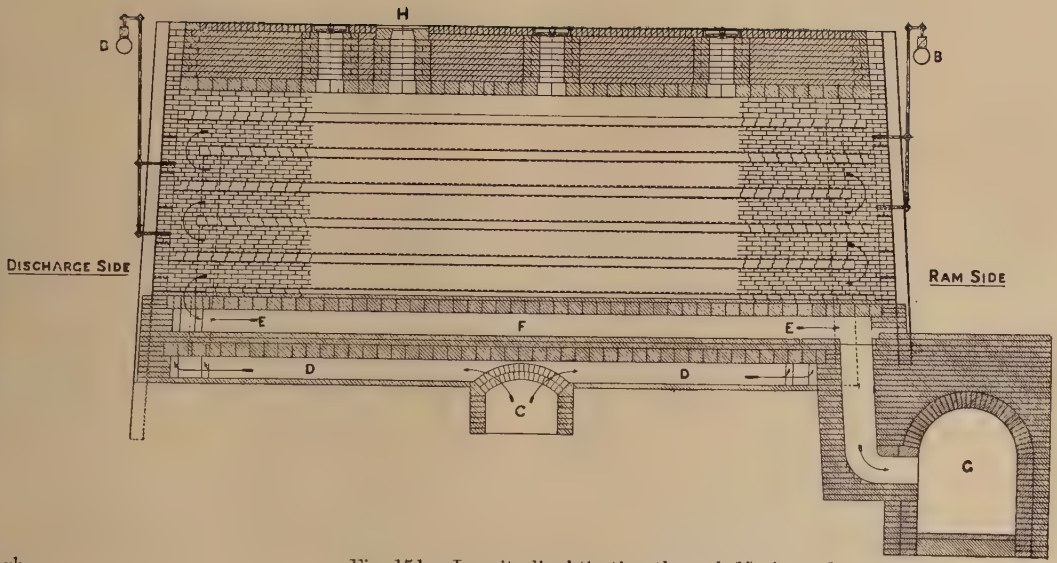


Fig. 151.—Longitudinal Section through Horizontal Heating Flues. "Semet-Solvay" Oven.

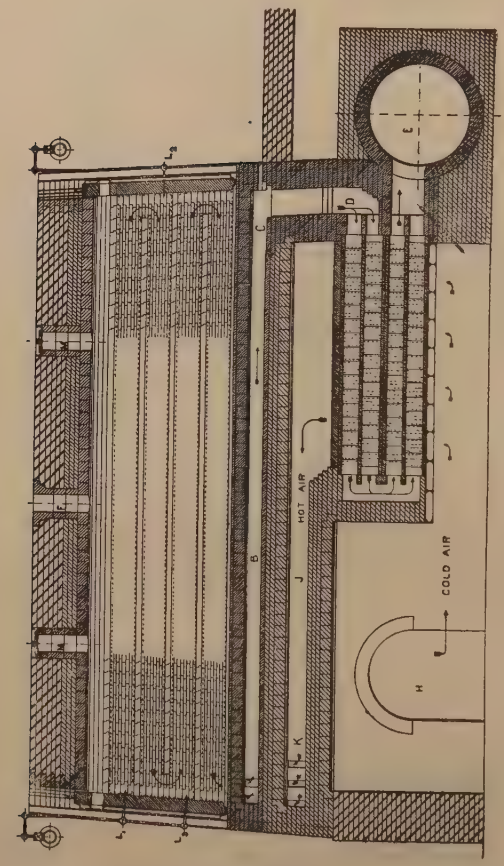


Fig. 153.—Longitudinal Section through Coking Chamber and Recuperators, "Semet-Solvay" Oven.

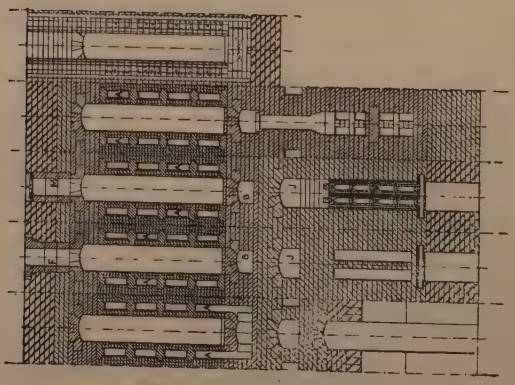


Fig. 152.—Cross-Section through Horizontal Heating Flues, "Semet-Solvay" Oven.

struction of such a method of designing the flues will be more than if the flues were part of the constructional walls, and served to heat two adjacent coking chambers, but the saving in cost of repairs, together with the enhanced stability of the structure, and the consequent immunity from stresses that are of necessity peculiar to the other form, will give this design a longer life for practical work.

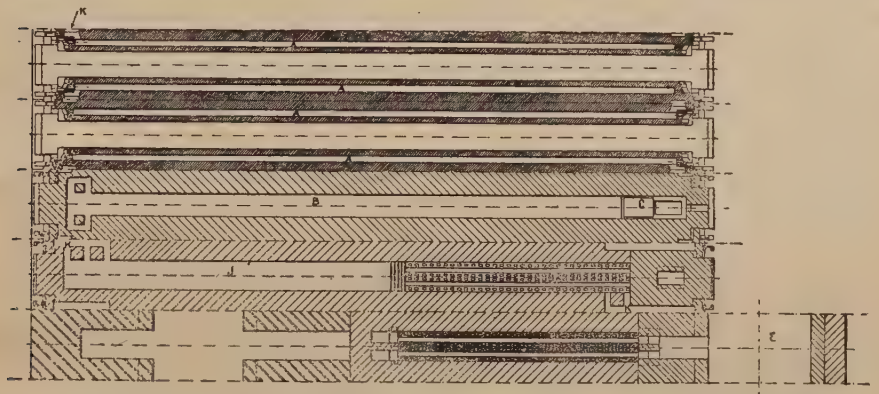


Fig. 154.—Plan of Coking Chamber and Recuperators. "Semet-Solvay" Oven.

These ovens when first designed were heated with gas and air, heated in the foundations by recuperators, as already shown in fig. 146; the waste heat, no doubt, was used to raise steam in boilers.

In the latest methods of construction of these coke ovens, there are four heating flues superimposed, and these are worked on two principles, either with a regenerator, or without, and the ovens are of two distinctive types, that is, they construct the ovens either as stated above with the flues independent of the constructional walls, or otherwise, thus making four distinct types; in their own words, the inventors describe them as follows :—

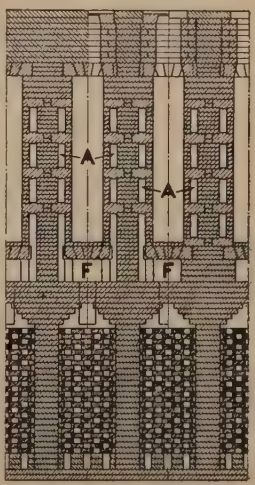


Fig. 155.—Cross-Section through Regenerators. "Semet-Solvay" Oven.

"(1) With the heating flues built into solid supporting walls, as shown in figs. 150, 151, 152. It retains the essential feature which distinguishes the Semet-Solvay from other ovens, namely, each oven has a separate set of flues and is separated from its neighbour by solid walls. With moderately dry coals containing over 27 per cent. of volatile matter the surplus gas is usually 30 per cent. of the whole.

"(2) With the supporting walls independent, figs. 153, 154, and 155. The heating flues and roof form a lining to the permanent oven structure; in fact, the flues can be removed and rebuilt without affecting the main structure. This type is more expensive, but is preferred in many instances, because of its substantial design and long life. Batteries are still at work which were built twenty-five to twenty-eight years ago.

"(3) Similar in construction to the first described, but with provisions for pre-heating the air to a greater degree, as shown in fig. 154. The air passes

through a continuous regenerator, and the yield of surplus gas is increased up to 60 per cent.

" (4) The same oven constructed with regenerators in the foundations, with the well-known alternative action and reversion."

The modern types are built with coking chambers, 8 feet to 10 feet high and 33 to 36 feet long, with widths varying from 16 to 22 inches, inside dimensions. The various widths are to suit the class of coal that has to be coked. Referring to figs. 150 to 155, the coking chamber is constructed with the permanent division walls, built separate from the walls of the longitudinal heating flues, A, (4 inches thick), which form the sides of the coking chamber, superimposed one over the other ; and above them are several courses of brickwork carrying the arched roof of the interior coking chamber, inside and immediately under the arch of the constructional furnace roof. Underneath, the coking chamber is built the sole flue, for heating the bottoms of the chamber with the spent gases from the side-heating flues. Outlets are formed in the roof of the coking chamber for the egress of the gases evolved during the period of carbonisation. These are collected into the hydraulic main, and taken to the by-product plant, stripped and conveyed back again to the oven by the gas main service pipe, fixed along each side of the top of the ovens, with branch supply pipes dipping to serve each flue where required.

In the " waste-heat " type of ovens the air for burning the gas is pre-heated by being drawn by means of the chimney draught through a series of channels, constructed under the whole battery of the ovens, where it is heated to about 300° C., and delivered through the upcast parts into the heating flues A. Gas is admitted to the heating flues, together with the regulated quantity of heated air, to the point L^1, and also at L^2 and L^3, fig. 153.

There are two outlets formed in the roof, which are stated to be there for the purpose of expelling the moisture given off from the coal during the preliminary heating after charging the coal into the coking chamber ; this is done by the box compressor and the coal is pushed into the oven by the machine through the oven door.

In the ovens of the recuperative type, shown in fig. 153, admission of gas and hot air is made to the top horizontal flue, as shown at L^1, and lower down at L^2 and L^3, fig. 153. The products of combustion travel through the fourth and lowest flue without any further supplement, and unite from both sides of the oven into the sole flue under the coking chamber ; they then pass by means of the main flue, D, fig. 153, through the continuous recuperator. These hot products of combustion of the heating gases travel along horizontal channels in the recuperator, and the air to be heated passes through " vertical holes, absorbing the heat in its passage." After the products of combustion have thus traversed the recuperator they are reduced to about 300° C., while the recuperated air has been heated up to 550° C. as it arrives at the burners. Each oven possesses its own separate recuperator. There is no reversal in this system of heating the air, the flow being continuous, both as regards the waste gases and the incoming air.

The inventors state, " In the Semet-Solvay oven, gas and air are admitted successively in the top and second flues ; gas only is admitted to the third flue. If the air be pre-heated to 550° C., the theoretical quantity for combustion produces a temperature far in excess of the temperature coke-oven bricks are capable of resisting. It is, therefore, clearly impossible to burn coke-oven gas with the theoretical quantity of air, and consequently an excess of air is necessary in each of the top flues."

This excess of air in the top flue tends to lower the temperature locally, but before the air makes its exit from the flue its temperature has been raised from 550° C. to about 1,000° C.; it then turns down and passes into the second flue. This is done with the object of lowering the temperature of the oven in the top region, so that the gases may not be damaged with regard to the recovery of the by-products. The regulation of the quantities of air and gas in the several flues when totalled at the finish is stated to be about the theoretical quantity of air for the amount of gas used. The substantial division walls in these ovens provide, beside constructional stability, the further economic value of conservation of heat, that is, when a chamber has been drawn and re-charged with cold coal, the heat required to re-establish the normal temperature in this class of construction will be more speedily attained than when the flues have no such substantial backing, therefore these ovens should be comparatively more rapid in their coking period.

With regard to the type of oven known as the "regenerative," shown in figs. 155 and 156, the waste gases and air are subject to reversal of the direction

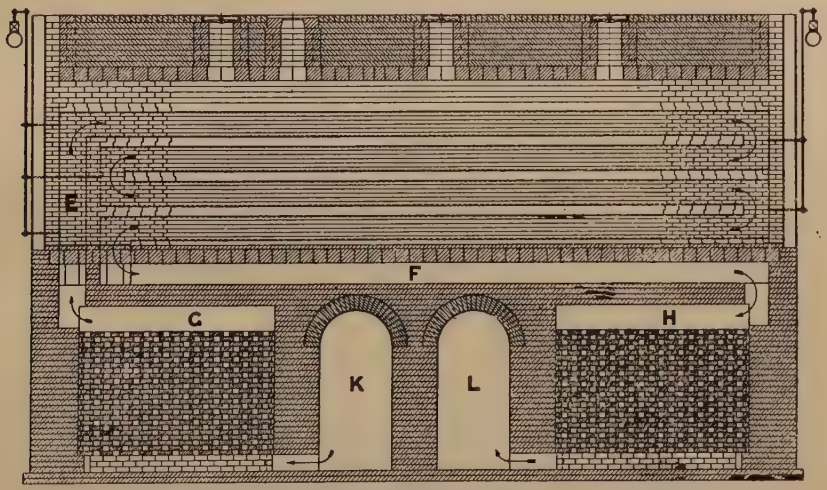


Fig. 156.—Longitudinal Section through Regenerators. "Semet-Solvay" Oven.

of their travel in the flues and regenerators of the furnace, according to the well-known principle introduced by Siemens.

In the oven constructed upon this principle, during one period of reversal the products of combustion of the gases in the heating flues after passing through the sole flue, F, under the coking chamber, travel into the regenerator, H, on the right, fig. 156. The vertical flue, E, is in connection with the regenerator on the opposite side, so that when a reversal takes place at the end of a period the heated air will return by the regenerator H, and the hot gases from the products of combustion will descend through the regenerator G, passing away by the conduit, K, to the chimney. All the admissions for gas and air to the heating flues are situated on the outside of the oven above the ground level, and are there under perfect control; sight holes are provided in every flue, so that observation can be made of the degree of heat obtaining, and this adjusted to the required intensity.

The latest development of the Semet-Solvay oven is the Piette type, which

has for its object the following, viz. :—Careful design for each individual installation ; careful application and control of temperature and regulation of gas

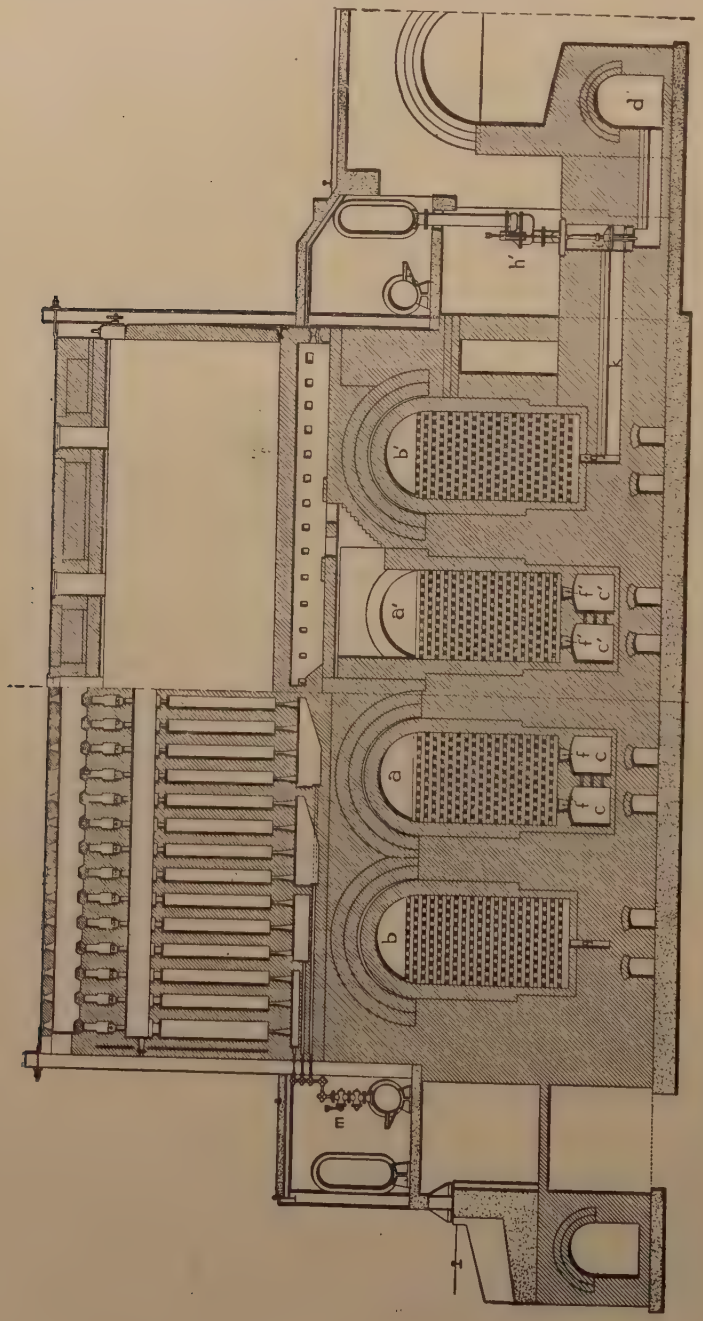


Fig. 159.—Elevation in Section. "Piette" Reversing Regenerative Oven.

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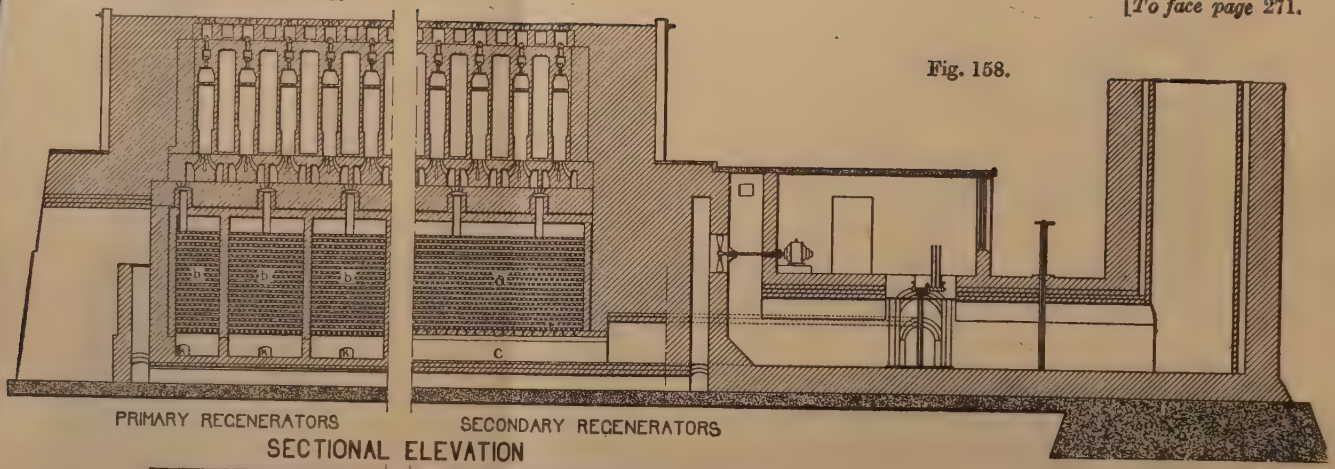
Fig. 158.



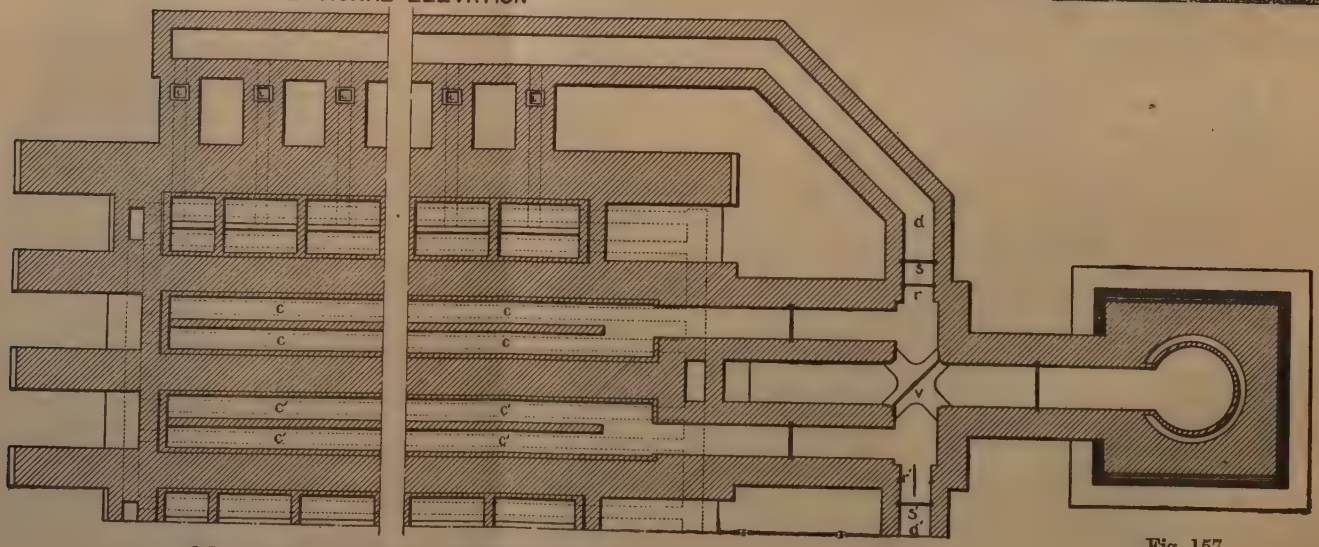


Fig. 157.

Figs. 157, 158.—Longitudinal Elevation and Sectional Plan of "Piette" Oven—Type "C" Modified.

and air, and the arrangement of the regenerator flues with the object of minimising the losses of heat by radiation.

The Piette Reversing Regenerative Oven (Type C) is constructed with vertical flues, with reversing arrangements, and transverse regenerators are placed in the longitudinal flues. Fig. 157 is a plan of the regenerators, and fig. 158 is a sectional elevation of the primary and secondary regenerators; fig. 159 shows a transverse section through the regenerators below and a longitudinal section through the heating flues on the left, and through the coking chamber on the right. Fig. 160 is a perspective view of section through coke oven and heating flues. This oven, as installed at Shelton Ironworks, Stoke-on-Trent, consists of two blocks of 12 ovens each, one block on each side of a central chimney. The oven chambers are 18 inches in width and about 11 feet in height. The ends of the heating walls are faced with heavy steel plates, wedged behind channel steel buckstays. The doors are made of cast steel, and operated by means of a chain sheave mounted over the centre of each door between channels supported on the buckstays; a drawbar riding on the sheaves runs along the full length of the battery, and is actuated by a motor, which gives it a stroke of about 11 feet 6 inches. The motor is controlled from any point by a pull-rope in tension, and is automatically cut out at the end of the stroke; it actuates a drum through a worm-reduction gear, on which two ropes are wound, one joined to the draw-bar and the other to a weight which counterbalances the door.

Fig. 160.—Perspective View of Heating Flues, "Piette" Oven.

To lift the door, the operator hooks a chain on to the top of the door, passes it over the sheave, and pins it to the drawbar; he then pulls the control rope; the weight of the door being balanced by this arrangement, a small motor only is necessary.

This oven possesses an improvement in the fact that it can be operated so that a sufficient quantity of the total gas used for heating is reserved for addition through the top burners, to consume the excess of air in the burnt products. In the half-wall working on the up-draught phase, if there be an excess of 25 per cent. of air, one-fifth of the total gas required is introduced into the down-draught on the other half-wall. This retarded combustion gives a high calorific efficiency, with only 4 per cent. excess of air going to the chimney, producing a very evenly heated wall. The coking period is reduced by this use of the top burners.

The gas collection main is of the liquor spray type, and is self-cleaning.

The heating wall is divided in length into two parts, the gas being reversed from one part to the other automatically. The heating flues are arranged in groups of four, out of distributing chambers *a*, *a*, fig. 160*a*; each chamber is

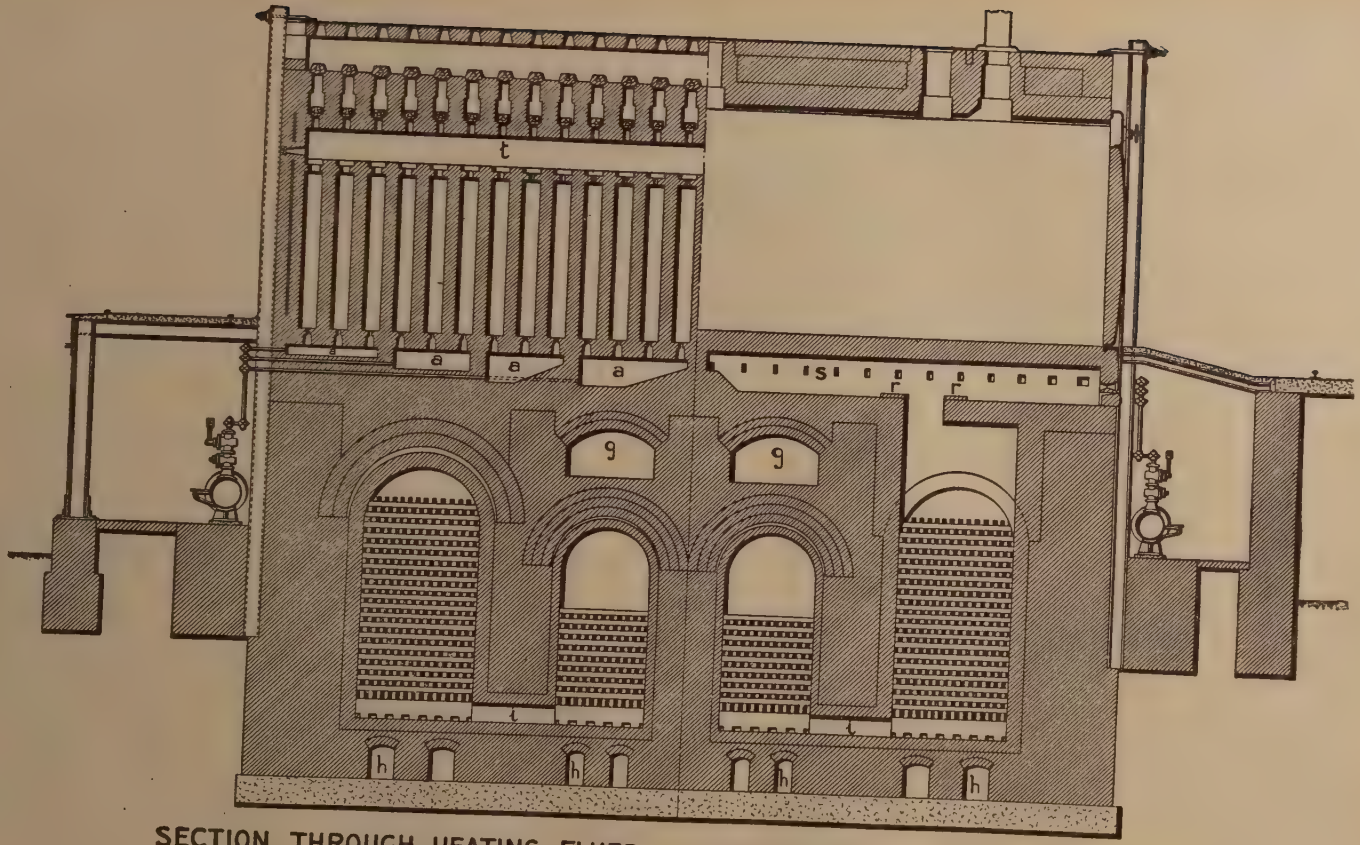


Fig. 160*a*.—Elevation in Section, "Piette" Oven, Type "C."

fed by a separate gas pipe fitted with a regulating cock. The regulation of the air supply is accomplished by means of dampers, *r*, fig. 157, which are placed at the inlets on the sole flue, s_1. It will be noticed that although the regenerators are constructed in longitudinal chambers, they are placed transversely across the ovens, the products of combustion crossing through the chequer work in a direction parallel with the oven, and travelling longitudinally only after arriving in the space free from the filling in the secondary chamber, in communication through the reversing valve with the chimney. The reversing valve connects one or other of the secondary chambers with the chimney alternately, and simultaneously admits the air inlet to the other.

The air for combustion passes through the flues, *g* and *h*, fig. 160*a*, previous to arriving at the reversing valve; while passing along the flues, *g*, it takes up the radiated heat of the sole flues; in the flues, *h*, it recovers the heat radiated in the foundations; the air entering the regenerators acquires a temperature thus of about 100° to 110° C. From the secondary regenerators the air goes through passages of varied predetermined areas, communicating with the primary regenerators, after which it rises to the sole flue to be distributed to the gas burners.

Some of the features claimed for this construction are, the flues in the ascending flow are remote from the descending flow, thus obviating short-circuiting. The gas also is evenly distributed by feeding it into compartments through separate pipes, each of which compartments serves three or four burners.

By the use of predetermined flue areas, dampers are rendered unnecessary.

By the arrangement of two conjoined regenerator chambers, the primary and secondary, with communicating passages between them, fig. 160*a*, which are suitably calibrated, the loss of draught along the length of the flue for burnt products is compensated, and an identical draught is maintained for all the ovens.

The air flues, *g*, fig. 160*a*, as well as the flues, *h*, effectively cool the products of combustion in the exit gases, and thus economise heat by reducing radiation losses.

By placing the regenerator chambers transversely, a stronger form of construction is claimed.

A test was made of these ovens erected at the Shelton Ironworks on November 8th, 1924, and the following are the results obtained by Mr. H. Morley, acting for the Shelton Co., and Mr. A. Williams, B.Sc., for the Semet-Solvay and Piette Coke Oven Co.:—

The battery consists of 24 Piette ovens, Type "C," erected under a guarantee to produce 1,300 tons of coke per week and 55 per cent. of surplus heat (guarantees exceeded by 33 and 14 per cent. respectively), provided the moisture did not exceed 13 per cent.

The gas made by the battery has a mean calorific value of 506 B.T.U. (stripped), but that used for heating is a mixture from the new and older batteries, and is of lower and variable quality.

Number of ovens discharged,	178
Average moisture in slack,	12·78 per cent.
Total dry coke produced,	1,733 tons.
Total dry coke per oven per week,	72 „
Average calorific value of heating gas (at 60° F. and 30 inches) per cub. foot,	459 B.T.U.
Calorific value of gas produced, before stripping,	550 „
„ „ „ „ after „	506 „

Gas used per ton of dry coal (at 60° F. and 30 inches),	4,493 cub. ft.
Total heat in stripped gas per ton of dry coal,	5,566,000 B.T.U.
Heat used per ton of dry coal,	2,062,300 „
Surplus heat per ton of dry coal,	3,503,700 „
Surplus heat, per cent.,	62·95 per cent.
Guarantees—Coke produced, exceeded by,	33·35 „
Surplus heat, exceeded by,	14·4 „
Temperatures—Heating flues,	1370° C.
Regenerators,	1130° C.
Burnt Gas to Chimney,	From 300 to 350° C.

Analysis of gas produced—

CO_2,	2·93 per cent.
O_2,	0·26 „
C_nH_m,	3·34 „
CO,	8·17 „
H_2,	53·90 „
CH_4,	26·75 „
N_2,	4·65 „

The Type " B " of this oven is also constructed with vertical flues, but is termed a " waste heat oven " ; fig. 160*b* is a section through the coking chamber ; fig. 160*c* is a section through the heating flues, and fig. 160*d* represents three sections transversely through the ovens and heating flues showing the method of introducing the gas and air. The centre line of the battery divides the heating wall into two equal parts ; each part delivers the products of combustion down the vertical flues (a, a^1) nearest to the centre line, fig. 160*c*, and then into its sole flue ; the flues of each half of the heating wall are divided into three groups, each receiving gas from the distributing chambers (e, e^1) fed by the pipe f. The air for combustion travels through the flue (h), and a series of transverse flues (g), fig. 160*c*, arriving at the distributing flues (i) fig. 160*d*, after having taken up the heat in its passage under the bottom of the ovens. Fig. 160*d* shows in detail the heating flue construction of this oven.

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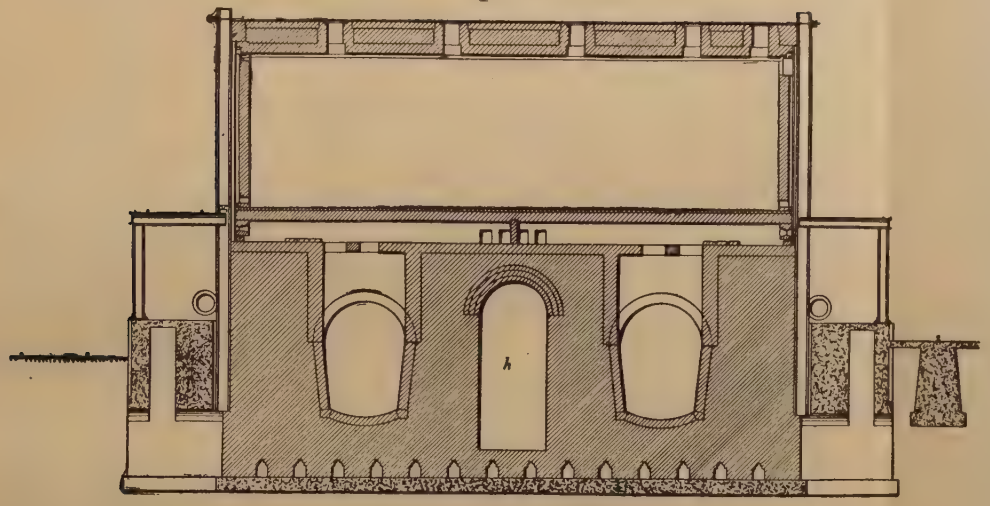
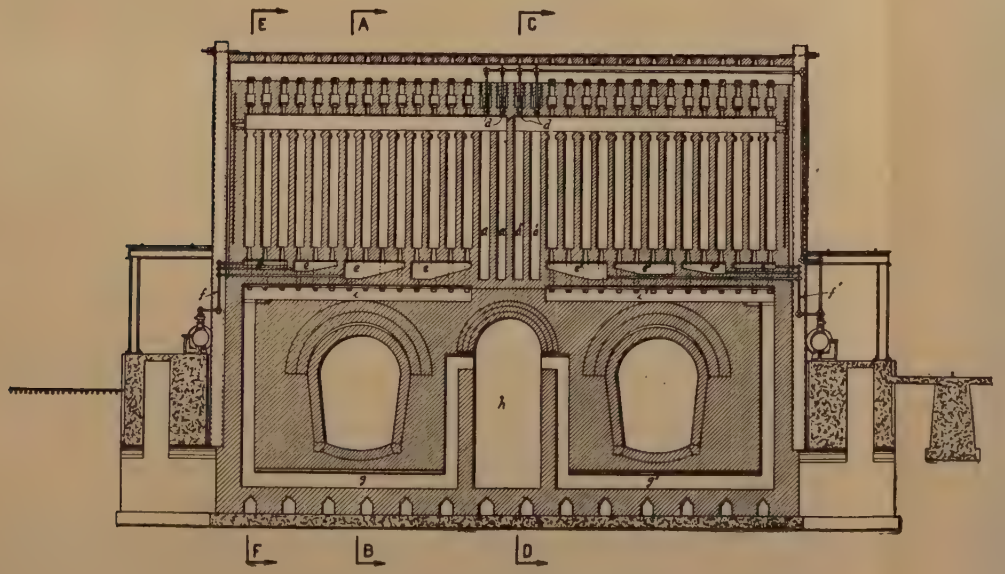
Fig. 160b.



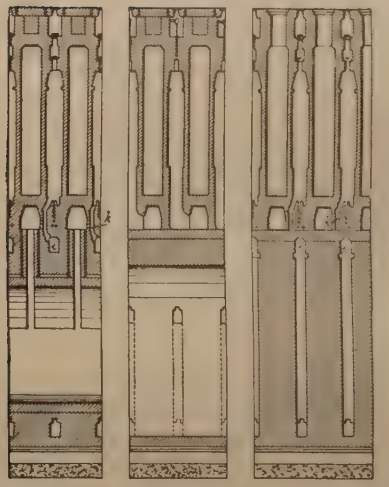
SECTION THROUGH OVEN CHAMBER



SECTION THROUGH HEATING FLUES

Fig. 160c. "Piette" Oven, Type "B."

Fig. 160d.



SECTION AB SECTION CD SECTION EF

CHAPTER IX.

COKE OVENS—VERTICAL TYPE.

The modern coke oven of the vertical type may date from the invention of the Brothers Appolt, and according to Percy this oven was first constructed by Messrs. Pinart Brothers at Marquise in the Department of the Pas de Calais in France, and was first lighted in September, 1857.

The **Appolt Oven** consists of several vertical retorts built into a rectangular brick chamber, measuring on the outside about 17 feet long by 11 feet 6 inches wide, and rising to a height of about 13 feet. The interior was divided into twelve compartments or coking chambers by division walls $4\frac{3}{4}$ inches thick; these retorts or coking chambers were constructed with their sides in a sloping manner so as to make the retort or coking chamber narrower at the top than at the bottom, and to allow greater ease for discharging the contents when the coking operation was finished.

The measurements of the interior of these chambers were as follows:—About 4 feet by 1 foot 6 inches at the bottom, and tapering up to 3 feet 8 inches by 1 foot 1 inch at the top. This tapering of the chamber was not necessary, as will be shown later on in this chapter, as the contraction of the coke makes ample allowance for the free discharge of the contents of the retort. These retorts or coking chambers were constructed individually separate, with flues surrounding them, as will be gathered from the vertical section, fig. 161, where *a*, *a* represents the retort or coking chamber, and *b*, *b* represents the surrounding flues. The outside walls were constructed hollow, the space being filled in with loose non-conducting material, in order that the expansion of the heated brickwork should not crack the main walls, which were not bound sufficiently by buck-stays, as obtains in more modern practice; this hollow space, although to a certain extent counteracting any expansion in the brickwork, nevertheless was a source of weakness, whereby the shape of the oven or coking chamber was endangered, the hot brickwork, expanding, pushed out the walls into the open space and cracked them. The cure was thus worse than the disease, the only achievement being to hide the cracks from view on the outside. The flues and the retorts or coking chambers were built of brick, the flues being supported by stretcher bricks running through the walls of the retorts, through the flues, and into the flue walls; by this method of construction the retorts were kept in their proper places; the stretcher bricks are shown on the section in fig. 46 at *d*, *d*. The retorts or coking chambers were charged from the top by the charging door shown in fig. 161, which is a vertical section through the ovens. The necessary contraction to form the neck of the retort is made by stepping or oversailing the brickwork inwardly. The bottom of the retorts or coking chambers had doors, hung upon hinges, for discharging the finished coke; these were hung to the cast-iron frames, at *u*, *u*, fig. 161, and supported by brick arches.

The partition walls of the retorts or coking chambers were pierced by openings, about 16 inches to 2 feet from the bottom, for the purpose of allowing

the gases formed in the retorts to escape into the heating flues surrounding the retorts or coking chambers; there were nine of these openings on the wide sides, and three on the narrow sides; at the lower end there were two rows of these openings, and towards the top there was one row only on each of the wide sides, with three openings only in each. The evolved gas passing through these openings was burned by atmospheric air admitted through openings in the side walls. The products of this combustion found their way to the exit flues and to the chimney, *g*, *g*, in the vertical flues; there were twelve vertical flues in all, and each flue was provided with a damper for the purpose of regulating the draught. In the discharging of the finished coke iron waggons were provided underneath for the purpose of receiving the charge and in order to prevent the coke from falling with too much force into these waggons, iron plates were placed in the walls immediately under the ovens, as shown at A in fig. 161.

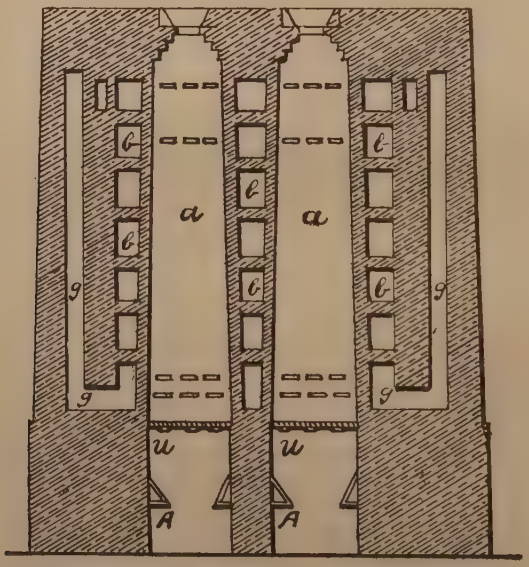


Fig. 161.—Vertical Section of "Appolt" Vertical Oven.

In heating up this coke oven in preparation for the coking operation, a temporary grate was placed on the bottom, consisting of iron bars, and above these a few firebricks were placed in order to prevent the clinkering formed in the preliminary fire from adhering to the permanent walls of the retorts or coking chambers; after the fire was lit it was kept going by fuel fed in through the charging door at the top; the products of combustion passing through the openings in the walls into the flues caused a current of heated air to heat the flues; this was continued until the whole oven had attained the requisite red-heat temperature, generally requiring ten to twelve days. The interior of the oven attained a temperature of from 1,200° to 1,400° C. (?), which is stated by Percy as being necessary before commencing to charge; in order to obtain a uniform temperature alternate sets of retorts or coking chambers were charged in the first instance, the temporary grate and firebricks being removed in those

compartments thus selected for the charging. The fires were kept going in the others for the space of about an hour, when they were likewise charged.

The gases evolved by the coal charged into the hot brickwork of the oven escaped into the flues surrounding the coking chambers, and thus kept up the heat.

The oven, when fully charged, was left for 24 hours, when the coke was withdrawn from the compartment first charged at the same hour on the previous day. The retort was then immediately re-charged, and so on in rotation until all the retorts in the oven had been emptied and re-charged. These retorts or coking chambers were capable of taking a charge of about $1\frac{1}{4}$ tons of coal, or a total of 17,000 kilograms of coal in the 12 chambers.

The coking process was a rapid one, and the coke produced was similar to that made in an ordinary horizontal oven of narrow dimensions, but by reason of the pressure of its own weight was much denser.

This method of making coke was undoubtedly a step in the right direction towards the quick output of ovens at the time when it was adopted, and there was also a larger yield per ton of coal carbonised, compared with the Beehive process of carbonisation, since no atmospheric air was admitted into the coking chamber in the Appolt system, and there was thus no loss from combustion. Had Appolt constructed his oven of wider dimensions than those given, 1 foot 6 inches to 13 inches, and had he retained the charge in it for 48 hours instead of 24 hours, a vastly superior coke would have been produced, and would have equalled that produced by the Beehive oven in quality. The influence of water on coking in the Appolt oven is stated to be as follows :—*

"When moistened coal is coked in the Appolt oven, as in the case of coal which has been washed in order to free it from earthy matter, the water thus retained, provided it be not excessive in quantity, is generally neither injurious to the process of coking nor to the quality of the coke. Water in the coal to the amount of 4 or 5 per cent. causes, it is said, more active combustion of the gases in the spaces surrounding the compartments. Certain coals, however, particularly the semi-coking, rich in oxygen (*demi maigres par exces d'oxygène*), do not cake so well, and yield less coherent coke when they are put into the oven in a fine state of division and moistened with, at the most, 5 per cent. of water ; but coals rich in carbon do not usually present this inconvenience, and as some of them increase in volume by carbonisation, it is necessary to counteract that evil, in order that the block of coke may leave the compartment without applying force, which might possibly injure the walls. The remedy is to add as much water to the charge of coal in powder form as will considerably increase its bulk, for which purpose the addition of 6 to 8 per cent. of its weight of water will be sufficient. Coal in fine powder thus treated will rather contract than swell during combustion, and, when carbonised in the Appolt oven, will yield dense coke, though in an ordinary oven the coke from it would be porous and light. The chief reason for such a difference in the character of the coke is, it is stated, the relatively greater height of the charge and the higher temperature in the Appolt oven. It is, however, added that there is not a great difference in density in relation to apparent volume between pieces from the bottom and top of a block of coke in the Appolt oven, though the former are a little denser than the latter. In a large number of cases it has been found that the same kind of coal yields denser coke by carbonisation in the Appolt oven than in other ovens." Some misconception must have arisen with reference to water mixed

* Quoted by Percy, *Bulletin de la Société de l'Industrie Minérale*, 1868.

with coal in increasing the bulk of the latter in the oven. The author's experience of adding 5 per cent. of water to a coking charge is that it tends to lessen the actual bulk in the oven by compacting the grains of coal closer to each other; but, on the other hand, it is correct that when water has been added the coke will be less in bulk, owing to the fact that the water will have evaporated, leaving the particles of coal very close together, therefore making a denser coke. The results obtained by the Appolt oven are, as far as can be ascertained, satisfactory; Messrs. Appolt published the description of their process in June, 1858, when the oven at Marquise had been in operation since the previous September, with the following results :—

"Each compartment contained from 1,350 to 1,400 kilograms of coal, that is, somewhat less than 1½ tons. The coking was completely effected in 24 hours. The operations took place during the day only, and required the services of four men. Belgian coking coal gave 80 to 82 per cent. of coke (which Percy does not regard as satisfactorily correct), and English coking coal gave 72 to 73 per cent. This yield is stated to be from 10 to 12 per cent. greater than that with ordinary ovens (Beehive probably). It is stated that the first experimental oven was erected at St. Avold, Department of the Moselle, and another larger oven subsequently erected at Saarbrück in Prussia. Yet another oven had been erected in 1856 at Rire-de-Gier, and was stated to have worked regularly during several months, but was afterwards discontinued owing to the high labour costs. The coke produced in the Appolt oven at Marquise was used in the iron-smelting furnaces of that establishment, and was said to be hard, dense, and close-grained good metallurgical coke. The oven was said to have cost 14,000 to 15,000 francs = £560 to £600, which seems to be remarkably cheap, considering its great daily capacity, upwards of 14 tons of coke.

About the same period or shortly after these trials of the Appolt oven a patent was applied for in Great Britain by George Hinton Bovill for practically the same invention, but lacking in practicability compared with the Appolt. Fig. 162 shows a vertical section through the **Bovill Oven.** The oven consists of a series of vertical chambers in some of which coke and gas are made, and the gas collected, while in others coke only is made (?), the gas being burned in and about the chambers. The chambers are constructed, like the Appolt oven, of brick, and surrounding each set of chambers, which are generally in threes, are flues where the gas passing from the chambers making coke only is burned for the purpose of heating all the chambers.

Referring to fig. 162, the chambers, *b*, are the coke ovens; those marked *d* are the gas retorts. Within each of the latter are inserted cast-iron flanged tubes, perforated for the purpose of collecting the gases; these tubes are formed in sections, the flanges forming the joints, *c*, of each section, fig. 162. They are made in three lengths, that is, in three pieces, each one-third of the length of the retort, the flanges being made almost the same width as the internal diameter of the retort or chamber.

It is stated that these tubes with their flanged ends are inserted for the purpose of facilitating the discharge of about one-third of the charge in the retort or chamber. This is effected by removing the cover, *t*, at the upper end of the retort and introducing a bar into the interior of the tube, fixing the two uppermost sections; the bottom of the retort is then removed, and the lowest section of the tube with the coke surrounding it falls out; the bottom of the retort is then replaced and fixed, and the two upper sections are lowered on to it, while another tube is placed in position on the top, and the top cover, *t*, fixed in its position again after the upper third

part of the retort has been replenished with a fresh charge of coal. The coke ovens are charged from time to time in a similar manner, but in the coke ovens tubes are not necessary, as bars are introduced to support the upper portion of coke for the purpose of discharging the lower section. The gas is collected by means of the pipes *f, f*, either from the top or bottom of the retort, but it is stated that the gas from the top of the oven is quite different to that taken from the bottom, the former being much richer, and producing "porous coke," the latter being poorer gas, with "denser coke." These differences in the products are due to the deposition of the tarry matters in the passage of the gas downwards through the incandescent coke, and *vice versa*. It is stated that the chambers or retorts making coke have "gratings" at the top, in order to let in air to burn the gas, at *h*. It is not stated what becomes of the gas carried away by the pipes, whether it is brought back to be used in the flues for heating the retorts or not; the fact that air is admitted to the top of coke chamber suggests that the gas is not so used, but that the gas from the other chamber only is proposed for use in heating the whole of the retorts, along with the heat developed by the burning of part of the coal in the top of the coking chamber.

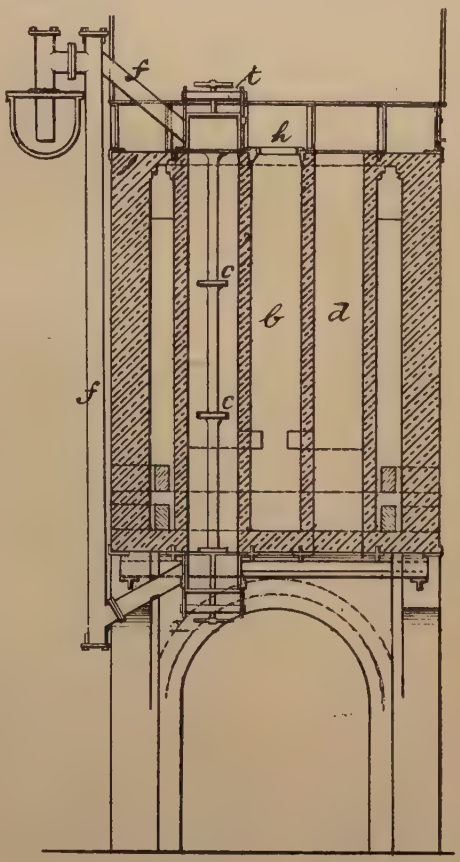


Fig. 162.—Vertical Section of "Bovill" Vertical Oven.

The proposition to admit air to the coking chamber to "maintain the necessary amount of combustion" would not result in such good coke as in the Appolt oven, nor would the yield be so large, since some portion of the charge of coal would be consumed. It does not seem possible to heat the two adjacent retorts sufficiently for the purpose of making gas, as the flues only surround three sides of them, and the coking chamber itself is only heated on two sides, or more particularly the two short sides or ends of the chambers, so that heating from the outside by means of the flues would be inadequate unless, as stated, the coal in the coking chamber was allowed to burn to supply the deficiency. The process of carbonisation must have been one of comparatively low temperature, and slow, whereas that proposed by Appolt would be a high temperature carbonisation, and rapid in action.

Another oven of the vertical type was proposed by Brandon, B.P. 340, A.D. 1883, to whom the patent was granted, the inventor being Emile Franzeu,

of Liege, in Belgium ; the **Brandon Oven** was designed on very similar lines to that of C. W. Siemens, who patented his invention in 1863. The oven proposed by Brandon was different in the matter of heating and saving the gas, but the general construction of the coking chamber was similar, and it was heated by means of flues surrounding it. Fig. 163 shows a vertical section through the coking chamber H, H. The coal is fed in through the door in the top at A,

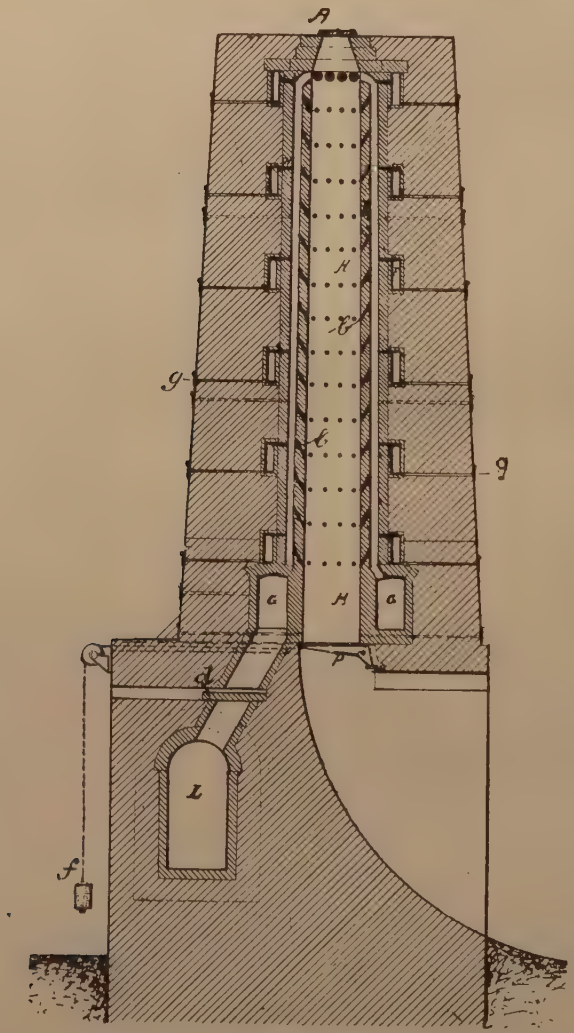


Fig. 163.—Vertical Section of " Brandon " Vertical Oven.

and the coke is let out by means of the door at the bottom P. The oven is heated by means of the gas evolved from the coal during carbonisation through the inclined channels, *b*, *b*, into the combustion flues surrounding the chamber, the air for combustion entering through channels in the walls *g*, *g*. The products

of combustion are drawn downwards to the chimney flue G, in which a damper, *d*, is placed on the exit to the chimney L. The door at the bottom of the coking chamber is actuated by the chain and balance weight *f*. These ovens are placed in rows, and the coke is discharged at one side down a curved shoot.

The oven patented by C. W. Siemens is constructed with vertical coking chambers or retorts, built with brick, and both coke and illuminating gas are proposed to be made in it ; the peculiar feature in the **Siemens Oven** is the addition of regenerators which are constructed vertically, adjoining the vertical coking chambers. The invention covers ovens in which the coke is partly burnt to give the necessary heat, and ovens are also described which are heated by gas consumed in external flues. Fig. 164 shows a vertical section through this oven ; A is the coking chamber closed on the top with a gas-tight door O ; this is constructed of rectangular section on plan. There is no door at the bottom, the coke falling into the space, P, filled with water, and forming a gas-tight water seal over the bottom of the chamber. By means of a butterfly reversing valve, D, air is supplied through one regenerator and gas is drawn

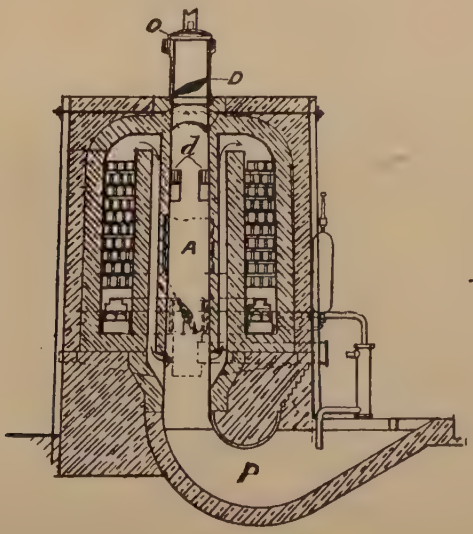


Fig. 164.—Vertical Section of " C. W. Siemens " Vertical Oven.

through the other regenerator ; this process is then reversed, the products of combustion being drawn through alternately for the purpose of heating up. The gas generated in the coking chamber may be extracted by means of flues, *d*, near the top of the chamber, or it may be compelled to pass downwards through the incandescent coke and into the combustion flues. In another modification, where air is not admitted into the retort or chamber, the egress is cut off and the gas is burnt in the flues themselves. Although Siemens claims to have made good coke by this means, it is difficult to see how his coke oven could stand the high temperature he claims to have developed with a rectangular oven ; the melting down of those parts where the gas and superheated air were first impinging would be expected ; the repairs, coupled with the cost of construction, would also seem

to make this process prohibitive as a commercial proposition. It is also difficult to see how the oven could be satisfactorily discharged without breaking the coke into breeze, and supersaturating it with moisture. There would be losses in this oven during carbonisation, due to the action of the steam produced in the water seal on the hot coke, and passing up into the region of incandescent coke, where CO and H_2 would be developed at the expense of a certain amount of coke; besides, this reaction would tend to lower the temperature of the chamber, thus discounting the very high temperature in the flues.

A vertical coke oven of a similar type to Siemens, just described, was designed by Bauer. The **Bauer Oven** was constructed for carbonising coal, and for either working with or without the condensation of by-products. The coking chambers were constructed radially in a circular group. Fig. 165 shows a vertical section through the vertical coking chamber, left hand, and through the combustion chamber, right hand. The retort, A, is charged through the door in the roof at *b*, and the coking chambers are arranged around a central gas-collecting

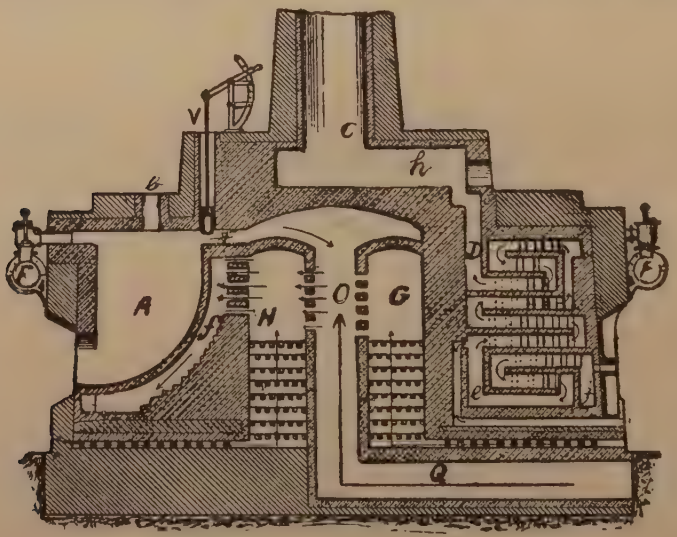


Fig. 165.—Vertical Section of " Bauer " Vertical Oven.

chamber O; there is also an annular gas and air-mixing chamber H. The gases given off by the process of carbonisation in the retorts are either drawn off by the gas pipes F, or are carried directly into the gas and air-mixing chamber through the channel in the direction of the arrows; if by the former, and the by-products are extracted from the gas, it is drawn into the pipe, F, by closing the valve V. After it has been condensed it is returned to the oven by the flue, Q, into the gas and air-mixing chamber. Air heated by passing through channels formed in the brickwork adjoining the external flues enters the chamber G, where it mixes with the gases coming from the chambers O; the combustion of the gas in the chamber, H, proceeds down the flues, *f*, behind and under the retorts, and ascends up the flues, *e*, into the chamber, D, constructed between the chambers or retorts. The products of combustion of the heating gases pass through the flue, *h*, into the chimney *c*. A set of these ovens was constructed at Dalry in Scotland for Messrs. Baird & Co. The ovens were about

6 feet deep by 1 foot 4 inches wide at the bottom, and tapering to 12 inches in width at the top. Each of the retorts or chambers held a charge of 2 tons of coal, and there being 40 chambers in the circular stack, the total charge was about 80 tons, which was worked off in 24 hours. The coke was discharged through doors at the side.

Another vertical coking oven combining some of the features of both Appolt and Bauer was designed by **Henry Simon.** Fig. 166 shows a vertical section through the two coking chambers or retorts. These ovens are slightly tapered inside towards the top, and are charged through a door in the roof, the coke being discharged through a hinged door in the bottom of each chamber. The space between the two chambers or rows of coking chambers forms in the upper part a general combustion chamber, with lateral flues; vertical channels are also arranged between the walls of the coking chambers, connecting with a continuous combustion chamber surrounding all the coking chambers. The gases from both the upper and lower part of the coking chambers go to the combustion chamber, and from these pass into a waste-gas collecting flue *t*, and from there into the regenerators, which are arranged to work either con-

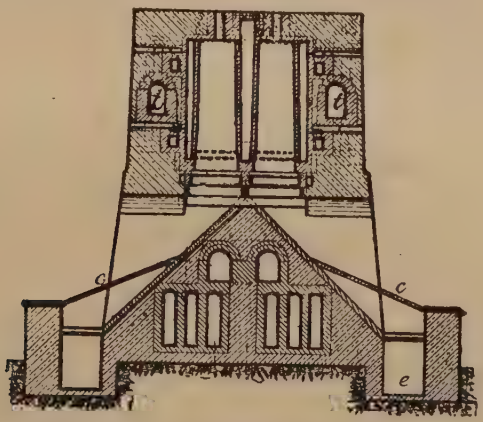


Fig. 166.—Vertical Section of " Henry Simon " Vertical Oven.

tinuously or are reversible. Arrangements are also made for drawing off the gas and condensing the by-products and returning the cleaned gas to be consumed in the combustion chamber.

The vertical coke oven designed by **Arthur Owen Jones** is constructed on a different principle from those already described. This oven, illustrated in fig. 167 by a vertical section through the coking chamber, is constructed with horizontal heating flues surrounding the coking chamber and superimposed; these discharge the products of the combustion of the gas into a common vertical chimney flue. The ovens are erected in a battery, and each one is heated by gas brought from a main service pipe carried up the outside of the front wall, with branch pipes to each of the horizontal flues *g*. The ovens are charged by means of a charging hopper, *p*, which runs on rails on the top of the ovens, through a door, *h*, on the top of the oven. The coke is discharged by means of a sliding door, *d*, falling down the curved incline underneath. The discharging door, having the whole weight of the coke upon it, is actuated by means of machinery at *c*. The gases evolved during the carbonisation pass away by the gas pipe, *a*, into the hydraulic main, *m*, and thence by the pipe, *a*,

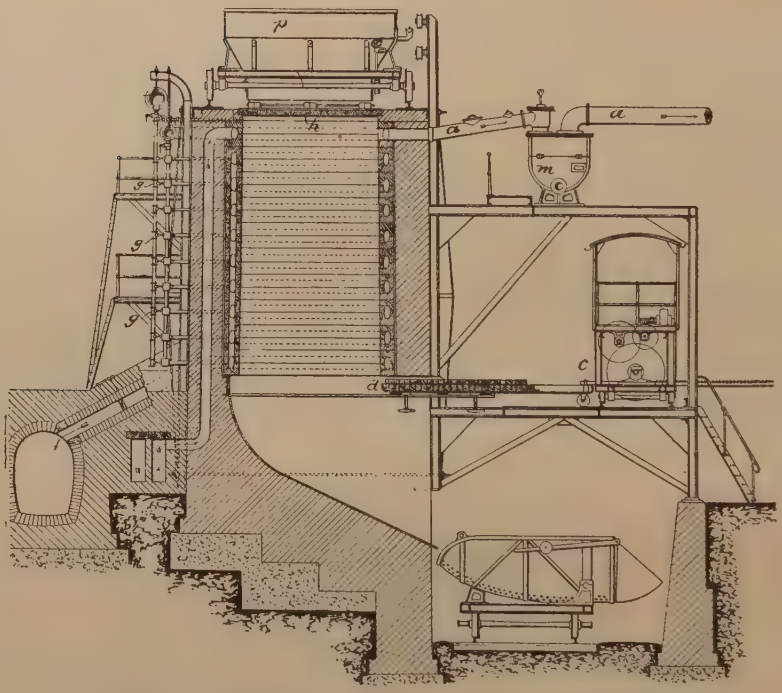


Fig. 167.—Vertical Section of " Arthur O. Jones " Vertical Oven.

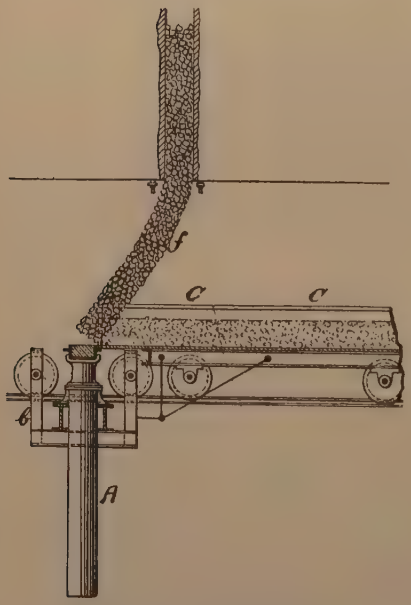


Fig. 168.—Lowering Coke from " Arthur O. Jones " Oven.

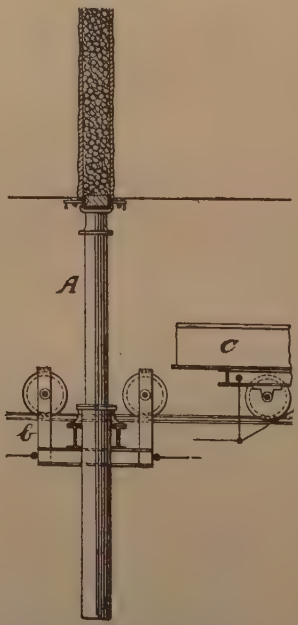


Fig. 169.—Lowering Coke from " Arthur O. Jones " Oven.

to the by-product plant. The gas, after it has been cleaned, is returned by a main pipe to the vertical service pipes shown on the front of the oven; each service pipe supplying a separate horizontal flue is furnished with a gas regulation cock.

The discharging of the coke seems to have given trouble, for in 1909 Jones applied for two patents to modify the apparatus for discharging these ovens. Figs. 168 and 169 show a method of lowering the door by means of a hydraulic ram *A*, which is capable of moving laterally on the trolley *b*, followed by the receptacle for the coke *c*, which also moves on a trolley on the same set of rails as the hydraulic ram. By this means, the door being lowered and the ram moved laterally, the column of coke bends as shown, coming out of the oven at *f*; but it is feared that this representation at *f* is practically impossible by reason of the superincumbent weight of the coke pressing from above, which would cause the coke to crush down suddenly upon the trolley and block up the space between the trolley and the underside of the oven; the trolley would thus be jammed, and either remain immovable, or by pressure the coke on the top of it would be crushed into breeze, before it could be released, unless the trolley was placed at such a distance below the sole of the oven as to take the fall of the coke, and be pushed in at such a rate as to spread the coke on it without heaping it up; such difficulties may have been overcome, but this method does not appear to be much better than letting the coke fall by its own weight down the slope, as shown in fig. 167. It was proposed to construct these ovens in batteries and to take a charge of 10 tons of coal each, to be worked off in about 36 hours. In order to keep the upper part of the ovens cool it was proposed to form channels running round inside the walls of the oven through which air is made to circulate for the purpose of preventing the decomposition of the gases as they ascend to the top of the coking chamber. Fig. 170 shows a horizontal section of this part of the oven, where the coking chambers are shown at *a*, *a*, *a*, and the air circulating channels at *b*, *b*, *b*; the inlet for the cold air is at *c*, *c*.

When the air has traversed the channels it is drawn off by the tubes *d*, *d*, and directed to the air ports of the heating flues, where it is used to mix with the gas for combustion; it is proposed to cover these pipes with non-conducting material to prevent radiation of the heat; even with this precaution it is questionable if the amount of heat that could be thus delivered to each separate flue towards the bottom of the oven would be worth the trouble taken, since the distance is great, and the subdivisions in the pipes numerous.

With regard to large vertical ovens constructed in batches, the difficulty of binding the brickwork in order to render them permanent and gas-tight is one that has been a problem of no small importance. The author found this out in the first experimental oven of the vertical type erected in 1904. Fig. 171 shows a vertical section through the narrow part of these ovens, *e*, *e*, being the coking chambers, *g* the channel supplying heated air to the gas burners at *h*, and *m*, *m* the coke discharging apparatus. Fig. 47 is a sectional plan of this oven. It was soon discovered in such a construction that the ovens which were about 6 feet long by 18 inches wide, and 20 feet high, could not be sufficiently bound unless very large and heavy ironwork was placed on the outside as it was impossible to insert tie-rods through the hot brickwork; cracks were soon developed, and proved the failure of such design from an economic and practical point of view. When, however, the author was called upon to design a vertical coke oven, for the carbonisation of coal from the Lanarkshire coalfield, this matter of construction was taken into due consideration, and a

different type of oven was designed. The facts laid before him were that this class of coal could not be carbonised for the manufacture of coke by ordinary methods, and he was informed that waggon loads of coal had been sent from the colliery of the Coltness Iron Company to several coke ovens of different types producing by-product coke, and when the author visited the Coltness Works he was shown the product produced in the ovens of the horizontal type; this consisted absolutely of powder in about the same condition of fineness as when the coal was sent away to be coked. The product was, however, coked, and small beads of coke throughout the mass shown by microscopical examination indicated that the coal was capable of fusing and forming coherent coke if the proper means were adopted. It was also stated that experiments had been carried out at certain of the coking establishments where this particular

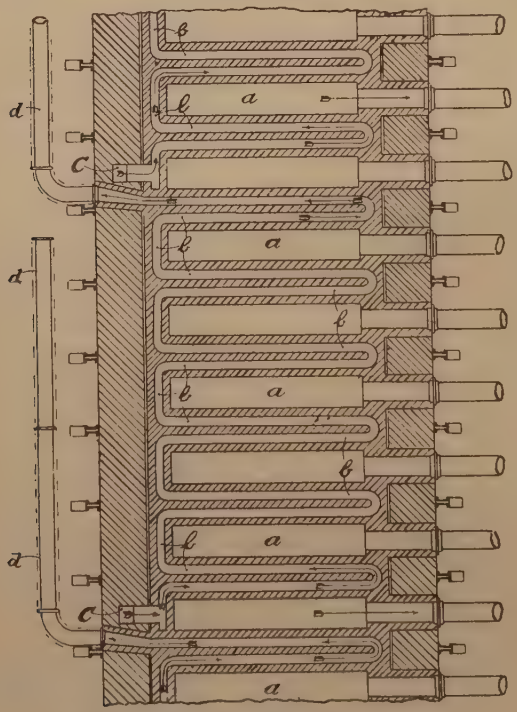


Fig. 170.—Plan of Cooling Apparatus for "Arthur O. Jones" Oven.

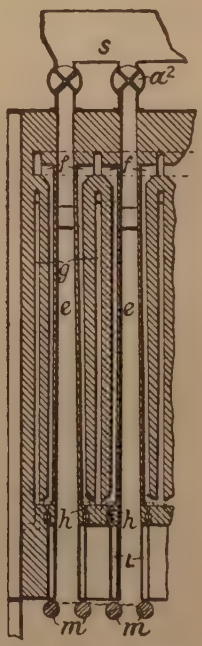


Fig. 171.—"Armstrong" Vertical Square Oven.

coal was sent, and that some charges in the oven were weighted on the top to give pressure during carbonisation; this had the effect of partially coking some of the coal but was impractical in the working of the ovens; the problem was, therefore, up to that time insoluble.

The object determined upon by the author as a means for the satisfactory carbonisation of this coal was to design a coke oven where pressure and very high temperature could be combined during the critical or melting period of carbonisation. To have applied these conditions to any existing oven would have been useless; he, therefore, designed the **Verti-Circular High-Temperature Oven**; fig. 172 shows a vertical section of this oven, and fig. 173 shows a sectional

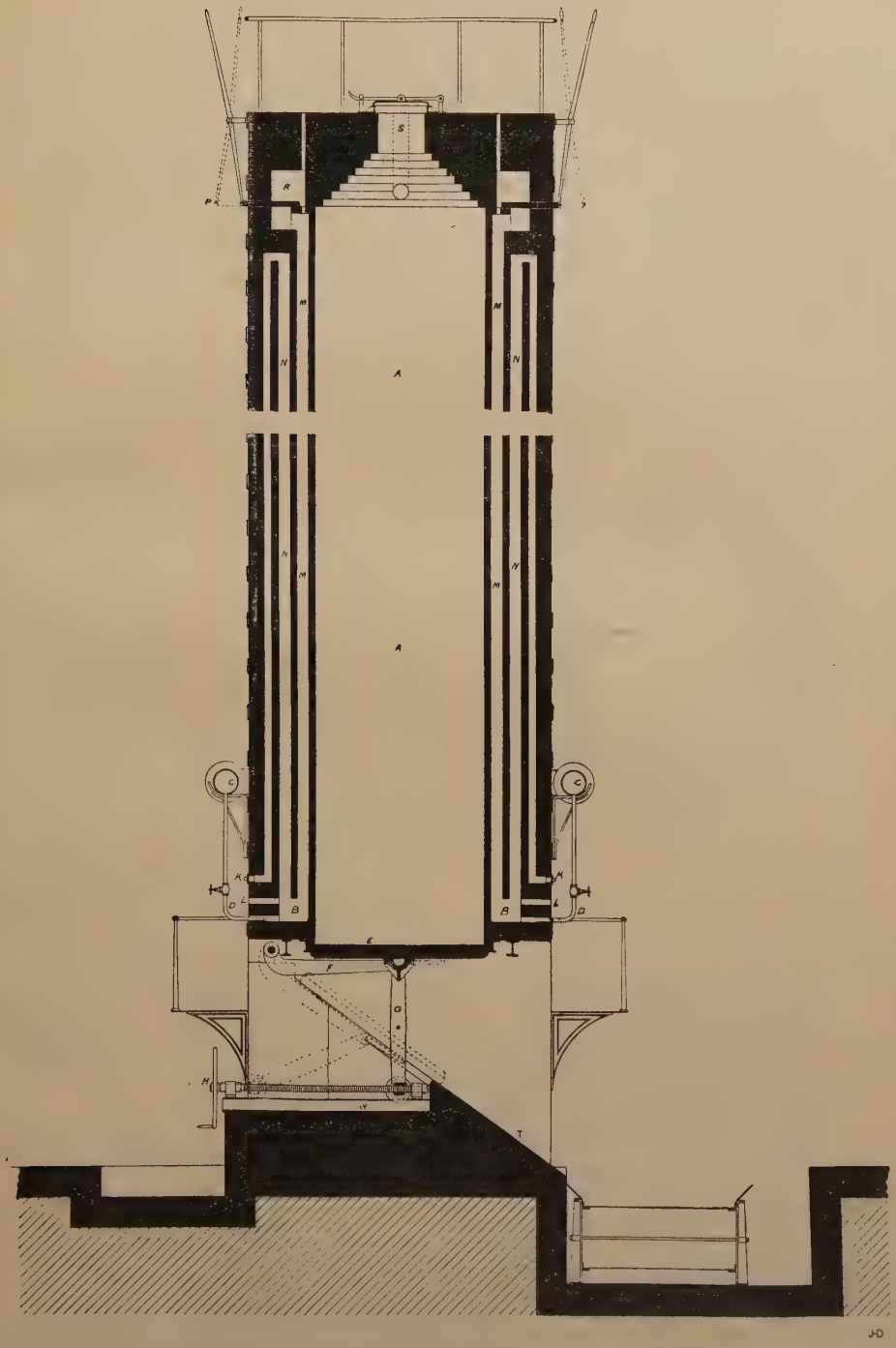


Fig. 172.—"Armstrong" Vertical Circular Oven (Vertical Section).

plan. The oven was erected at the Coltness Iron Company's works at Newmains, Lanarkshire, and a trial was made with a charge of this same coal that had withstood all means hitherto employed to coke it and to produce a coherent commercial article; Dr. W. Carrick Anderson was employed to superintend the trials and to report upon the results. When the first charge was put into the oven it was loaded in at the top through a gas-tight door; it consisted of about 4 tons, and after firing the oven for 48 hours it was opened at the bottom, and a charge of first-class hard, dense coke was obtained, but was in smaller pieces than that from other coking coal usually used to make metallurgical coke; the author was highly complimented on the occasion by the manager, Mr. Russel, on the results of the trial. In order to test this oven further with a comparative charge of coal that was being then coked in horizontal ovens, a waggon load was obtained from Messrs. Pease & Partners, Ltd., of Darlington, from which a charge was placed in the oven, and the following is the report of this trial and the results obtained, as described by Dr. Anderson :—

" I have to report as follows on the results of the trial made of the Armstrong Patent Vertical Coke Oven at the works of the Coltness Iron Co., Ltd., Newmains.

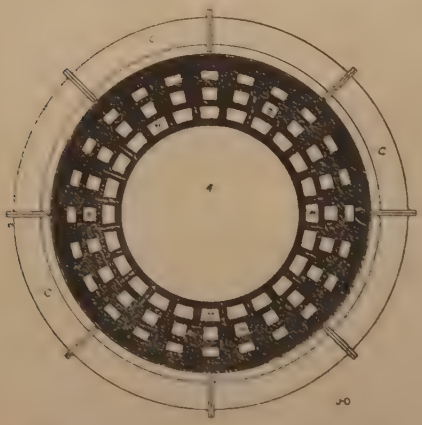


Fig. 173.—" Armstrong " Circular Oven (Sectional Plan).

" The oven, which is of the vertical type, is 30 feet in height and circular in shape, and is heated by blast furnace gases from the adjacent coal-fed blast furnaces. These gases are burned in vertical flues arranged round the periphery of the oven by means of air which is previously heated to a very high temperature by the escaping waste gases. The oven is thus a regenerate one of a particularly economical type as regards construction, and exceedingly efficient in its utilisation of the heat generated in the combustion flues, as may be gauged from the fact that, although the oven was working very hot internally, the brickwork on the outside was just sensibly warm to the hand, while a large amount of heat was still available in the outgoing gases for use under boilers.

" The oven was charged at 6 p.m. on 13th November with washed coal from Messrs. Pease & Partners, Ltd., Darlington. The weight introduced was 4 tons 16 cwts., containing 5·74 per cent. of adhering water, equivalent to 4 tons 10½ cwts. of air-dry coal. The coke was drawn at 10.30 a.m. on the 15th, the coal having thus been 40½ hours in the oven.

" The weight of quenched coke drawn was 3 tons 13¾ cwts., containing 0·62 per cent. of moisture, equivalent to 3 tons 13¼ cwts. of dry coke, or 80·9 per cent. of the air-dry coal charged.

" The crucible assay of the coal in the laboratory gave a result for coke = 71·92 per cent., so that the practical out-put from the oven exceeded the laboratory result by nearly 9 per cent.

" The coke produced was of a very superior quality. Most of it was of a fine silver-grey colour; for a 40-hour coke it was hard and strong, and the porosity was very even. Dark coloured and soft pieces were very few, and

little difference, if any, could be detected between the stuff drawn from the upper and lower parts of the oven, showing very uniform heating throughout the flues. The average length of the pieces was considerably greater than can be got from the ordinary horizontal ovens, and as the width of this oven could, in my opinion, be yet further increased for use with very strong coking coals, it would appear to be possible by its means to obtain by-product coke of a length hitherto only to be got by the use of the Beehive oven.

"The oven charge attained a very high temperature during coking, and to this, along with the resistance offered to the escaping gases by the high column of coal, consolidated under its own weight, is to be ascribed the very large percentage yield of coke obtained. The high temperature and the pressure easily got in this oven make it admirably suited to the treatment of coals which are not cokable in ovens of the ordinary horizontal type, and a very good quality of coke has been manufactured in it from Scotch coals usually regarded as non-coking. On the other hand, by reason of the very complete control which can be exercised over the gas supply, the oven is not less adaptable to the coking of coals, such as those of Durham, which are better suited to a more gradual treatment at lower temperatures, while again the large capacity of the ovens renders it possible to give a prolonged period of coking, and still to maintain a large weekly output from each unit of the plant.

"I am,
"Yours faithfully,
"W. Carrick Anderson."

Appendix to Report on Trial of "Armstrong" Patent Coke Oven.

	Tons.	Cwts.
Weight of Washed Durham Coal charged into Oven,	4	16
Deduct adhering Moisture, 5·74 per cent.,		5·5
Net Charge of Air-dry Coal,	4	10·5

Coke drawn from Oven:

	Tons.	Cwts.
Weighed in Waggon,	3	13
Specimens additional,		0·75
Total Weight,	3	13·75
Deduct Moisture, = 0·62 per cent.,		0·50
Net Dry Coke,	3	13·25

Dry Coke drawn = 80·9 per cent. of Air-dry Coal.
Laboratory Result = 71·92 per cent. of Air-dry Coal.

Analysis of Coal.

		Air-dry.	Moist, as charged.
Volatile Matters	Gas, Tar, etc.,	27·09 per cent.	25·52 per cent.
	Water,	0·99 „	6·73 „
Coke,	Fixed Carbon,	66·78 „	62·91 „
	Ash,	5·14 „	4·84 „
		100·00 per cent.	100·00 per cent.
	Total Sulphur,	0·928 per cent.	0·874 per cent.
	Caking Index,	—	18
	Coke,	—	Swollen & bright.
	Ash,	—	Reddish white.

Analysis of Coke.

Moisture,	0·62 per cent.
Gas and Tar,	1·37 „
Sulphur,	0·776 „

W. Carrick Anderson.

Since coal was first made into coke and until the present time, Beehive coke has been, and still is, the standard for quality in all the markets of the world, and generally brings a higher price than by-product coke.

It was for many years believed that by-products such as gas, tar, ammonia, etc., could only be saved in the manufacture of coke by sacrificing its quality, and to a certain extent this is perfectly true, because the method adopted in the modern by-product ovens for the manufacture of coke differs very materially from the process in Beehive ovens.

In a well-constructed Beehive oven the coal is coked by the heat developed from the combustion of the escaping gas in the upper part of the oven. The crust of incandescent coke, which is formed on the surface of the coal, soon turns hard and dense, producing considerable resistance to the swelling up of the coal as it softens beneath it, and as this crust thickens its weight and resistance give rise to pressure underneath, which influences the coal undergoing carbonisation at that period when it is in the soft and plastic condition, preventing the development of large gas bubbles, and tending to consolidate and compress the cellular structure of the coke. These circumstances also favour the deposition of the heavy hydrocarbons or tarry matter from the gas, building up the interstices and strengthening the walls of the coke cells by the addition of pure carbon, producing thereby the highest quality of coke.

In the modern horizontal by-product oven these necessary conditions are absent. The ovens are constructed for producing coke quickly; they are, therefore, made very narrow, generally from 16 to 22 inches wide, so that thick crusts of coke are never formed, as in the Beehive oven, and, as the coking proceeds from both sides, the escaping gas does not penetrate any mass of uncoked coal, so that very little of the heavy hydrocarbons are deposited; they are carried away by the gas and condensed as tar; it is, therefore, difficult in these narrow ovens to form this rich quality coke. Attempts have been made to remove these disadvantages from the horizontal by-product ovens, and with a certain amount of success, by pressing the coal into a mould before placing it in the oven; by this means a heavier charge has been secured, but as the pressure is released when the charge enters the oven, its effect is considerably discounted; when the charge of coke is drawn it is observed that there is a hollow space down the centre of the column of coke, proving that there has been no pressure upon the coke at the critical moment of its formation, when pressure is mostly required.

Certain coals, such as those of the Lanarkshire coalfield previously referred to, containing large amounts of oxygen and hydrogen, cannot be coked in the modern by-product horizontal oven, for two reasons, viz., the chemical combination of the above-mentioned gases at the coking temperature abstracts so much heat from the coal that no coherent coke is formed. It might be possible with improved heating arrangements to compensate for this thermal loss, but the result would be a speedy destruction of the oven. The second reason is that, even given a high temperature, it is also necessary in order to coke these coals successfully to maintain a considerable pressure during the coking period.

It has been the object of the inventor of the verti-circular by-product coke oven to manufacture high-class coke under the same conditions as in the Beehive oven, from any kind of coking coal, but saving all the by-products, and giving a larger daily output per oven, with a larger quantity of coke per ton of coal than is possible with the ordinary by-product oven.

This new oven is totally different from the modern by-product oven. Instead of being horizontal it is vertical, so that the full weight of the charge maintains a considerable pressure during the coking period. It is constructed circular for various reasons, some of which are: cheapness in construction, greater stability, uniformity and quickness of heating, and large output. It is cheaper to build than horizontal by-product ovens, costing on an average about 10 to 20 per cent. less, because the circular form can be bound on the outside with simple metallic bands, and requires only one-quarter of the expensive foundations of horizontal ovens. The outside walls are constructed with common bricks, built independently of the fire-resisting material forming the inside lining, in which the heating flues are constructed. The oven is recuperative, and is heated with a portion of the gas from which the by-products have been extracted. The gas is burnt with heated air and the recuperators are designed to serve two purposes; firstly, to keep the outside walls cool, and, secondly, to heat the air for combustion. Upon reference to the accompanying vertical section, fig. 172, it will be noticed that the cold air flue marked K enters the outside wall near the bottom of the oven, and ascends to near the top, thereby keeping this outside wall cool. The flue then turns round and descends as shown at N, N behind the heating flue M, M; the incoming air is thereby heated to a temperature of about 1,000° C.; it then meets the gas which is introduced by the cock D, fig. 172, and enters the combustion chamber B. The flames and the products of combustion ascend the heating flues M, M. Upon reference to the plan, fig. 173, it will be noticed that these flues are formed as segments of an arch surrounding the coking chamber A. This has been found to be the strongest form of coke oven construction for maintaining pressure during the coking period. It is evident that the pressure must be considerable in the interior of the mass of coal, because the coal is heated all round and the coke forms a ring round the core of uncoked coal. As the heat penetrates this ring of coke the interior mass of coal commences to soften and swell, and being unable to expand owing to the pressure above, the gas cells are, therefore, formed of much smaller dimensions, and denser coke is made than under the conditions prevailing in horizontal ovens.

In this new oven the heavy hydrocarbons contained in the escaping gas must pass through the superincumbent uncoked coal (which is from 30 to 40 feet high), where they are deposited under similar conditions to those already referred to in the Beehive oven, forming the very best quality of coke free from ash.

As these ovens are constructed of large dimensions, the smallest size not being less than from 36 to 40 inches wide, the coke is obtained in pieces resembling those from the Beehive ovens, fig. 44.

Owing to the pressure prevailing in this oven during the coking period, as stated above, it is found when the oven is discharged that there is no hollow space in the interior of the column of coke as occurs in horizontal ovens.

The inlets of both gas and air are regulated with the utmost ease and precision, and after the adjustment has been made for the proper temperature, this oven works with litte or no attention.

By the novel recuperative principle the consumption of gas for heating

this oven is reduced to the minimum, allowing a large amount of surplus gas (after that required for heating the oven) for other purposes, such as producing power by gas engines, heating furnaces, boilers, etc. The waste heat from the combustion flues is collected and conducted under boilers for raising steam; this is the only by-product coke oven constructed upon recuperative principles where the waste heat can also be used for this purpose.

The cold air passing through the air flues in the outside walls, as already stated, keeps them cool, preventing undue expansion or radiation, and securing the stability of the oven upon permanently cold brickwork.

The heating flues which surround the coking chamber are made in the form of arch bricks; they, therefore, cannot move out of place, but form an interior lining to the outside permanent walls. These flues are built independently of the outside walls, and the oven is, therefore, very easily and expeditiously repaired or relined, and as each oven is isolated, the stoppage for repairs only affects one oven.

As these ovens are discharged automatically without the entrance into them of any ram or other machinery, the walls are not subjected to any injury.

The ovens are generally constructed in a row with an elevated tramway running along the top for coal waggons, by which they are charged through the gas-tight door in the top, marked S, fig. 172.

The coke is discharged simply by opening the door at the bottom, marked E, by means of the screw and hand wheel H. This door and its fittings are very substantially constructed. It is supported upon strong hinges F, and the struts marked G. The latter are framed together and provided with flanged wheels at the bottom, which run upon rails marked W. The coke is either received upon a travelling conveyer or into a specially constructed waggon, in which it is quenched.

The gas is taken away from the oven at the top in the ordinary way, and passed through condensers, etc., to obtain the by-products. A portion is then returned to the supply pipe, C, surrounding the oven, for the purpose of heating the oven, as already described. Inspection tubes, marked L, are inserted in the combustion chamber for the purpose of observing the temperature. Corresponding tubes, marked R, are also inserted in the main flues at the top. These flues also contain regulating dampers marked P.

This oven has been erected for the purpose of coking Lanarkshire coal requiring high temperature and pressure. Coke has been made in it from this coal, as stated above, equal to the best Beehive coke, although the same coal has been tried and has proved a failure in horizontal by-product ovens.

This oven is one of the best by-product coking ovens that can be used for the fat, gaseous coals of Northumberland and other districts, as well as for the ordinary coking coal of Durham, Yorkshire, South Wales, and elsewhere.

The oven may be automatically discharged by the apparatus shown in fig. 174.

The chambers are filled in the ordinary way by the top, and when the coke is ready for discharging, an iron cylinder or tank, movable on wheels Q, Q and on rails, V, V, is brought under the bottom of the oven chamber, and the piston J J is elevated inside it. The head of the piston lifts the door, E, slightly off the bolts that fasten it; these bolts are then drawn, and the piston is lowered until the head arrives at the bottom of the cylinder or tank. Then the forks Y, Y are driven into the mass of coke, dividing it, holding the upper portion in the oven, while the lower portion in the cylinder or tank is further

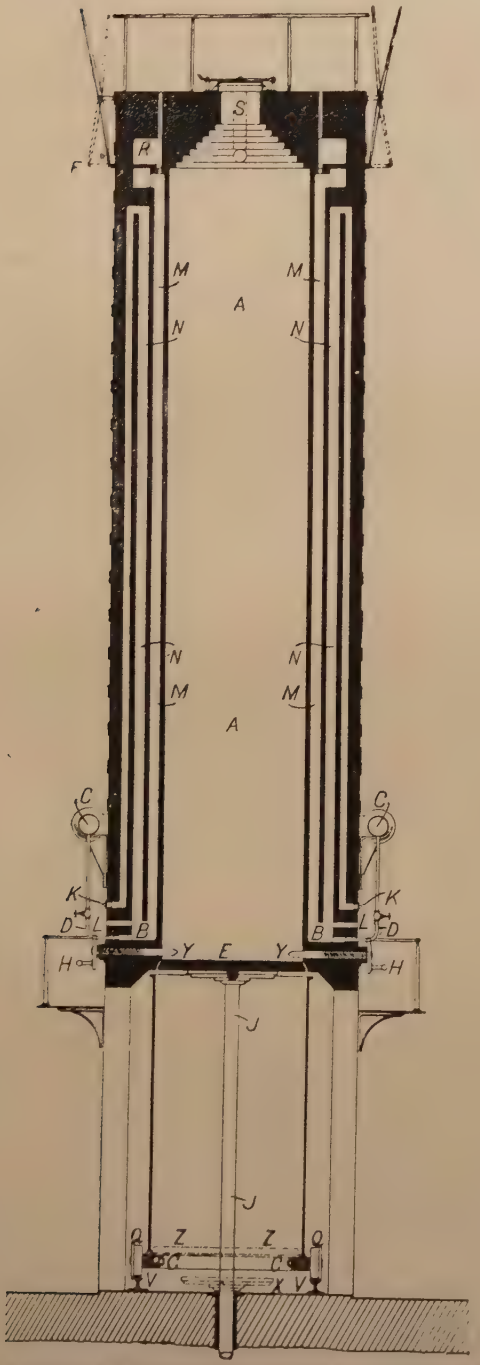


Fig. 174.—"Armstrong" Vertical Oven with Automatic Coke Discharge.

lowered, until the bottom, E remains on the snugs G, G; the head of the piston is then lowered to the position shown by dotted lines at X, X. The cylinder or tank with the hot coke in it is then moved away to be chilled, while another is placed under the oven chamber, and the piston, with a loose door upon it, is elevated until it touches the coke; the forks are then withdrawn, and the coke remains on the door E, the operation being repeated until the oven is emptied; the piston then replaces the door, E, in its place, the bolts are fastened, and the oven re-charged.

After the coke has been cooled inside the cylinder it is brought alongside the railway trucks, and a piston is applied inside which lifts the contents into the truck, without breakage or handling whatever. The whole of the coke is thus saved and no breeze made, and being cooled out of contact of air, it has the bright silver colour of Beehive coke, and is in large pieces; as much as 80·4 per cent. of Durham coal has thus been placed in trucks as best foundry coke.

One of the important features of this new oven is the fact of the gas ascending through a cool column of coal, by which the maximum amount of ammonia is obtained.

The yield of coke by this new vertical by-product coke oven from Durham coal was 9 per cent. more than the fixed carbon content of the coal, and from 3 to 5 per cent. more than obtained in horizontal ovens, and 15 to 16 per cent. more than obtained in Beehive ovens from the same coals.

CHAPTER X.

DISCHARGING AND QUENCHING OF COKE AND DISPOSAL OF BREEZE.

When the hydrocarbons have been expelled from the coal in the coke ovens, the ovens are discharged; this is accomplished in the horizontal type of oven by means of machinery which pushes the coke out on to the cooling bench; in the vertical type it is done by gravitation, that is, by releasing the door at the base of the oven and allowing the coke to fall out by its own weight; or it is let down by means of a ram, acting inversely, that is, the pressure of the coke pushes the ram shaft into a cylinder filled with liquid, which is gradually expelled, while the coke is received into a cooling box.

The method of discharging the Beehive oven is to quench the coke inside the oven by throwing in water, and then raking out the coke. In all the processes adopted for the manufacture of coke it is essential that the coke shall be quenched as quickly as possible, because, when the oven is opened and the incandescent coke is exposed to the atmosphere, combustion is instantly produced, with the resultant loss of coke and discoloration on the surface; in fact, if bright silvery appearance is required, it is imperative that the coke be quenched out of contact with air, and before it has been exposed thereto, and with perfectly clear and clean quenching water. This matter of quenching for the production of clean, bright coke has been a problem for many years, and a considerable amount of skill and apparatus have been required in the development of processes for this purpose, which have been more or less successful; the problem is one around which many difficulties hang, although to the ordinary mind the quenching and discharging of a coke oven appears quite simple, and it is indeed extremely simple if coke is produced without regard to outward appearance. The problem in the case of Beehive oven coke is the simplest, and is of easy accomplishment; by quenching the contents inside the oven a rich, lustrous, bright, silvery appearance is produced, and as this quality of coke was produced for many years in the Beehive ovens prior to the introdution of by-product ovens, it became the standard for quality in the markets of the world. When the by-product oven was introduced, and the hot coke was pushed out on to the bench into the atmosphere and quenched with water not often clean, a dirty black appearance was produced that prejudiced this manufacture perhaps more than it deserved in the eyes of purchasers; the price was always lower than for coke produced by the Beehive process, possessing the bright, clean appearance. In order, therefore, to compete in the market with the Beehive product, much thought and work have been expended in experiments to produce an article resembling the Beehive coke from the by-product ovens; but, as explained in another chapter, the ordinary by-product coke oven cannot produce an article equal to the Beehive oven, for the reasons given, which are briefly:—The latter process is conducted under totally different conditions to those obtaining in the horizontal by-product oven, while it is practically impossible to quench the coke before it has had contact with the atmosphere, that is, inside the horizontal coke oven; on the other hand,

the most up-to-date method of quenching it is extremely good, and greatly in advance of previous methods of doing this on the sloping bench, with all the evils attendant upon it, resulting in the production of bad-coloured coke and a relatively large amount of breeze, the latter being produced to a large extent by tumbling the coke over and raking it down the sloping bench.

Fig. 175 shows the side elevation for a modern **Coppée method of quenching the coke** as it is pushed out of the oven by the ram ; the quencher consists of a metallic frame with steel piping made in the shape of an inverted U ; the inside surface of the piping is perforated with small holes. The quencher travels

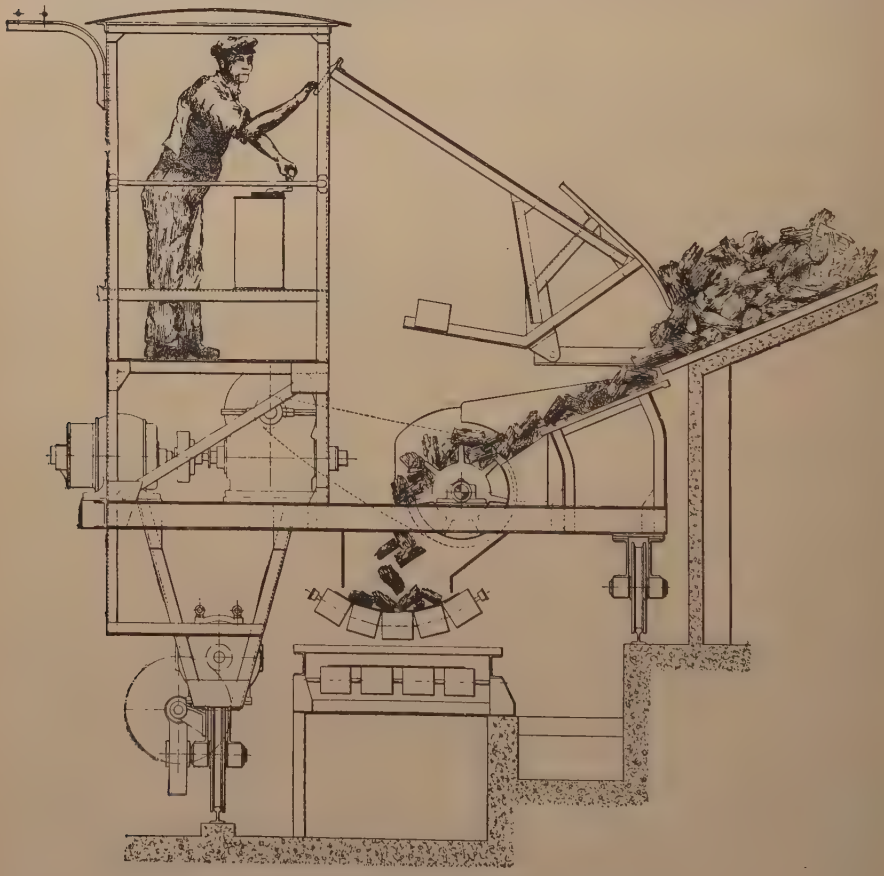


Fig. 176.—Transfer Car at Work (Semet-Solvay Co.).

along the batch of ovens upon a rail fixed on a level with the top of the ovens, and the water is conveyed to the quencher from the water main by means of an armoured flexible pipe, at a pressure of about 80 lbs. It will be seen from the illustration that the coke passing through the quencher falls on to the sloping bench ; the upper portion will, therefore, suffer from the impact on the bench, and disintegration will take place, resulting in the production of breeze.

Another **quenching apparatus** made by the **Semet-Solvay Co.** is adapted to run on the rails in front of the ovens, as well as on rails over the roof of the

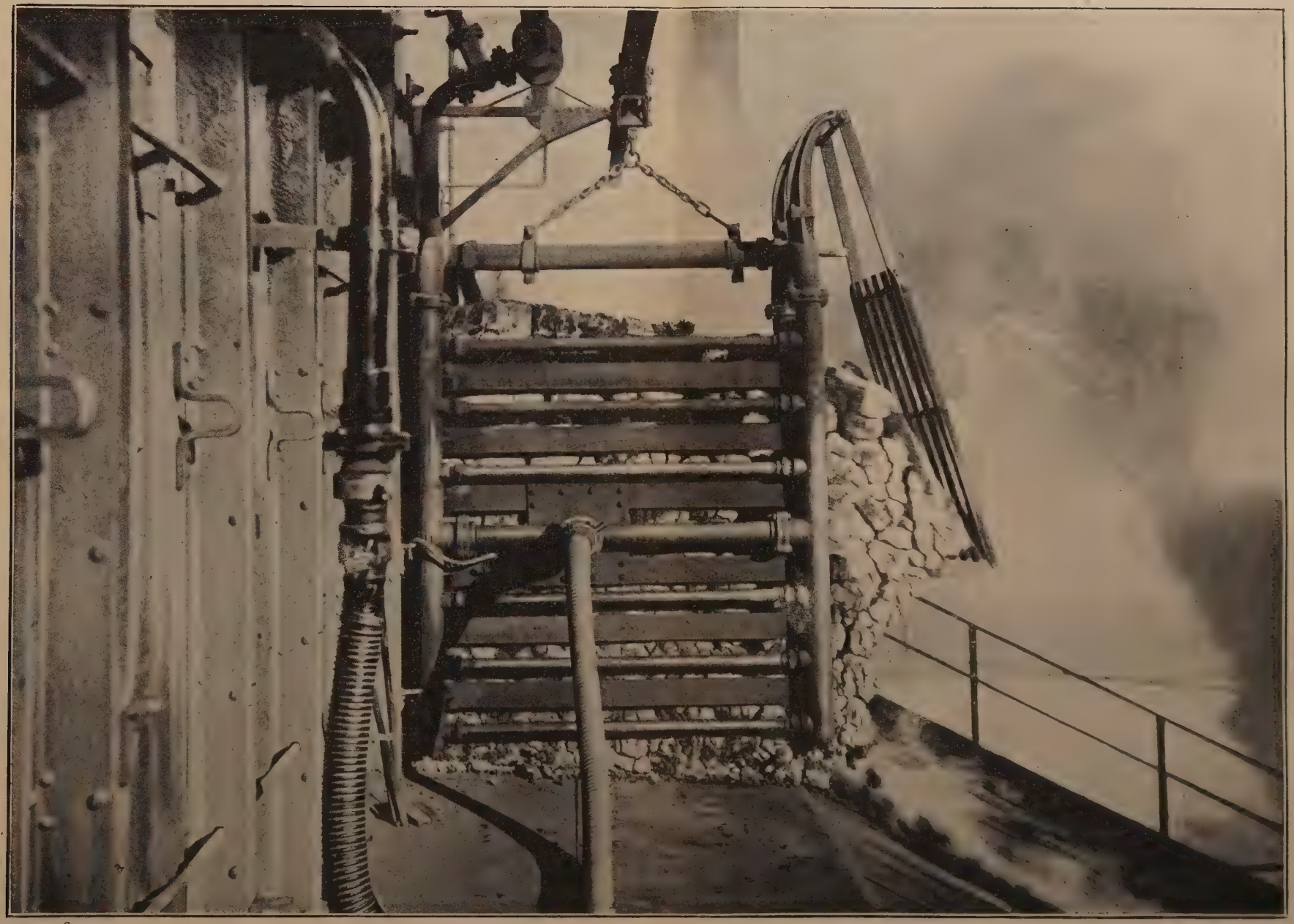


Fig. 175.—Side View of " Coppée " Quencher.

ovens. The coke passing from the quencher must be loaded direct into trucks. Fig. 176 shows a method employed by the Semet-Solvay Co. The sloping bench being lined with steel plates, the coke slides down either into barrows, if required

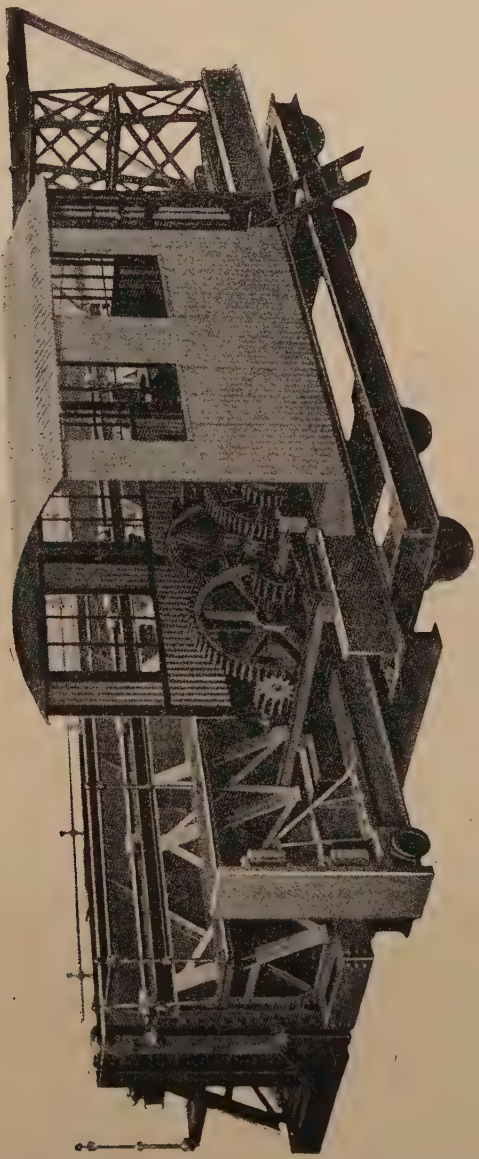


Fig. 177.—Coke Oven Ram for Discharging Coke (Coppée).

to go direct to the furnace, gates being placed at the foot of the slope for this purpose; or, if the coke is to be carried away by a collecting conveyer, the gates are dispensed with, the coke then being automatically conveyed away on the conveyer, as shown in fig. 176. Fig. 177 shows on the right the **Coppée coke**

ram used for discharging the horizontal coke oven, and on the left the coal-compressing box; this machine traverses the whole bench of ovens, on the opposite side to that to which the coke is delivered to the quenching apparatus, and after the ram has pushed out the coke in the first oven it is moved along to the next, and so on, along the bench of ovens.

The ram has a front plate, which enters the oven, after the oven door has been raised, the ram being actuated by a long shaft upon which is mounted a rack, propelled by means of a pinion-toothed wheel, usually driven in modern plant by means of an electric motor. In the case shown in the above illustration there are separate motors for each motion; the ram in its forward motion moves comparatively slowly, whilst the backward motion is a quick one, withdrawing the ram from the oven. Great care has to be exercised in these operations, especially where the ovens are old and the brickwork uneven, in case a projecting edge of a brick in the side walls becomes engaged either with the moving mass of coke or the head of the ram; serious damage to the interior of the oven may arise from this cause, which would be difficult to repair without interrupting the coking operations. It is the fact of thus discharging the oven by means of a ram pushing out the coke that the construction of the oven must be executed with the utmost care and precision, and with the best materials procurable, so as to prevent inequalities in the walls. Firebricks which do not expand or contract, nor soften with the high temperature attainable in the regenerative type of by-product oven, must be used.

Discharging and Quenching Coke from Vertical Ovens.—The discharging of vertical ovens is the simplest operation in the manufacture of coke; it is generally performed by opening a door at the lower end of the oven, the coke falling out by its own weight; but as this gives rise to the formation of breeze, other means are adopted to let the coke descend gently out of the oven into waggons, or a travelling conveyer, or into a quenching and cooling box, where the minimum quantity of breeze is made, and where the coke is quenched and cooled under similar conditions to that obtaining in the Beehive ovens. The vertical oven also provides means for the manufacture of coke upon similar lines to those of the Beehive oven, and producing coke in the same shaped pieces; and where it is quenched and handled, as will be presently shown from vertical circular ovens, a product is obtained similar in every respect to that made in Beehive ovens, but with the additional advantage of a largely increased yield from the same weight of coal, ranging often to as much as 16 per cent., together with all the valuable by-products—ammonia, benzol, etc. Figs. 167, 168, 169, 178 and 179 show in vertical section the means employed by Mr. Jones for discharging the coke from his vertical coke oven (B.P. 11,660, A.D. 1906), which consist of a sliding door, *d*, actuated by a rack machine, *c*, running along rails at the rear of the ovens; when the oven is charged, and during the coking period the door, *d*, is fixed by means of clamping screws; when the coke is withdrawn from the oven, the doors are slid back by means of the machine, the coke falling by its own weight down the slope into the truck. No doubt practical difficulties were encountered in the operation of this machine, as, the next year, 1907, Mr. Jones designed another apparatus (B.P. 6921), where means are provided for lowering the sole plate of the oven by a screw mounted on a truck running on rails under the ovens, by means of which the sole plate is lowered, and is then drawn forward by a rack.

Two years later Jones made further improvements in the apparatus for discharging the ovens (B.P. 19,812, 1909), in order to save the breakage of the coke consequent upon its descent from the oven, B, down the shoot into the

truck. He employed hydraulic rams to lower the sole plate of the oven, figs. 178 and 179, so as to allow the coke to fall gently upon a platform arranged to receive it. The hydraulic rams support the "discharge door," *a*, which is shown in position by the dotted line at the base of the oven. When the oven is charged the ram is fixed by clamps or other means. The ram is shown at A in fig. 168, and is capable of being moved from oven to oven on the rails *b*; mounted on this rail track is a trolley or coke conveyer, *c*, figs. 168 and 169, of sufficient length to take the total charge in the oven, which is run out beneath the ovens by means of cables *d*, fixed to the carriage *b*; when this is done, and the trolley is clear of the bench of ovens, the hydraulic ram is applied to one side of the trolley, as shown in fig. 179, whereby the trolley is tipped up and the contents discharged.

In this system of vertical by-product coke ovens, the ovens are built of several long, narrow, rectilinear retorts, constructed side by side, presenting difficulties in discharging peculiar to themselves, as will no doubt be gathered from the description given above of the alternative methods that were proposed to deal with the problem.

Fig. 174 shows the method designed by the author (B.P. 4427, 1911), where the coke oven is circular on plan, in one instance, and in ovens or retorts similar to those described above, where several narrow longitudinal ovens are constructed side by side. By this

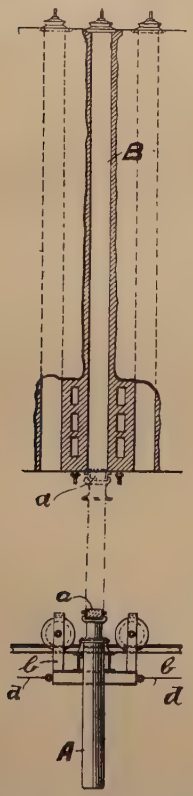


Fig. 178.—Platform Discharge for Coke from "Jones" Oven.

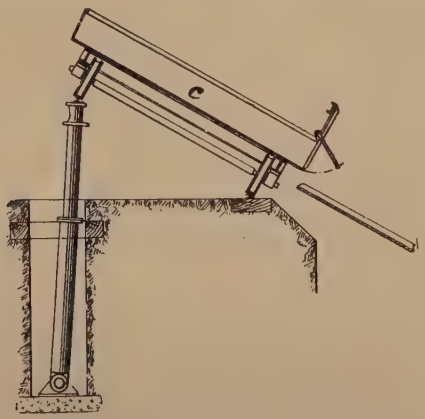


Fig. 179.—Discharge of Coke from Waggon. "Jones" Oven.

means the obvious breaking of the coke by releasing the door at the base of the oven or retort is obviated; it is obviated by means of forks worked upon a horizontal plane, immediately above the sole plate door at the base of the oven, and penetrating the walls, entering the body of the column of coke, and fixing it in position. A ram working perpendicularly inside a caisson or cylinder lowers the door so that the coke on the top of the door will follow it. With reference to fig. 174, A is the oven full of coke ready to be discharged, J is the head of the ram, E is the sole

plate or door of the oven, which is not attached to the ram, but which, when the plate is put into position before the oven is charged, is fixed by means of clamps, etc. When the coke is discharged the caisson or cylinder is brought immediately under the retort or oven and secured, the ram is then raised from under the rails, as at X, to beneath the oven door, as at E ; the clamps holding the door in position are now released, and the full weight of the charge of coke above the door is supported by the ram, which is gradually lowered by turning an outlet cock on the hydraulic cylinder, when the ram head with the charge of coke on it, which may be one-fourth, or one-third, or any proportion of the entire charge, is now lowered into the caisson ; the forks, Y, are inserted into the charge of coke still in the oven, the ram is then lowered again a few inches to clear the oven base, when the charge on the oven door is received on the projecting ledges, C, C, inside the caisson ; the ram is now lowered quite clear of the caisson, which is then pushed out on the rails, V, and quenched ; another caisson with another oven bottom in it is put into position, and this operation is repeated until the oven is completely discharged ; when this is accomplished the ram is raised with a door on top of it up to the base of the oven, where it is clamped and fixed ; the ram is now lowered and the oven re-charged.

In this operation it will be observed that the coke is never subjected to any disintegration or crushing, being gradually lowered into the caisson, where it is quenched, also avoiding oxidation and discoloration, and breakage into breeze. The ram is operated by the weight of the coke when it descends ; the liquid in the cylinder of the ram piston is compressed into another compartment, and when at its lowest position the cocks are closed ; when the ram piston is required to be raised the liquid is gradually let into the cylinder by means of the cocks above mentioned.

Discharging Coke from Beehive Ovens.—Beehive ovens are generally constructed in a bench or row, side by side, and often back to back against a similar bench ; they are generally constructed with a door in front, and a charging door in the roof. Several methods for discharging these ovens and for quenching the coke have been proposed from the earliest times ; some of these propositions have been designed to save breakage of the coke, and others for the purpose of quenching it more efficiently.

Generally, the coke from Beehive ovens is quenched inside the oven, immediately it has finished coking. A hose pipe is inserted into the upper part of the doorway, which is built up loosely with brickwork ; the coke inside is subjected to a thorough drenching with clean water all over its surface ; as the coke on the surface chills, the water penetrates lower down, producing a large quantity of steam ; in fact, 90 per cent. or more of the water applied for quenching the coke is evaporated into steam ; some carbon monoxide gas is formed, carrying away with it a portion of the carbon by the well-known reaction between water and incandescent carbon, producing hydrogen, carbon monoxide, and water vapour ; these find their exit into the chimney attached to the oven ; when this operation has been completed, the remaining bricks in the doorway are removed, and a toothed instrument in the form of a rake is inserted, and the coke disengaged in lumps from the mass inside, and pulled out. This method is a wasteful one, and productive of a large quantity of breeze, which is not very saleable on account of the large quantity of ash mingled with it ; its presence is due to the combustion of the coal on the surface of the charge, whilst undergoing carbonisation. Certain forms of cradles or frames made of iron, connected with chains, and laid on the bed of the oven previous to the insertion

of the charge of coal, have been tried, but the difficulty of detaching these from the bed of the oven, on the one hand, and the great amount of power required to extract them with the adhering coke, together with the wear and tear, on the other hand, resulted in the abandonment of this method in favour of the ordinary one of raking out the coke.

The latter method, when conducted by an experienced coke burner, and carefully managed, can be performed with a minimum of loss in the form of breeze, where a shovel is used inside the furnace for removing the coke, instead of dragging it out the whole way with a rake.

A novel means of quenching the coke in Beehive ovens was proposed in 1895 by J. T. Key (B.P. 10,356), where the water or steam was conveyed to the bottom of the oven by means of pipes, into flues under the floor of the oven.

With coke which has attained a high temperature during carbonisation, and which has been quenched inside the oven slowly, by this means it is possible to eliminate a good proportion of the sulphur; but this is, however, always attended with a loss of carbon, and it is, therefore, generally more economical to quench the coke rapidly, and to see that before it is taken out of the oven it has been so cooled that it will not subsequently take fire when piled in a heap. It is surprising how small a quantity of water is retained in coke when rapidly quenched and using a good volume of water, because the initial heat in the interior of the mass of the lump of coke remains, and evaporates the surplus moisture still retained in the exterior parts. Some specimens picked up, which have been quenched in the oven, are found to be practically dry.

The handling of coke on the bench every time it is turned over with shovel or rake produces a certain amount of disintegration, resulting in coke dust and breeze. A large proportion of the breeze from the Beehive oven, where the coke is carbonised by internal combustion, as already stated, contains a great quantity of ash, which makes it of little value unless it is put through a process of cleaning, to eliminate the ash; but, on the other hand, that produced in by-product ovens, where the process is conducted out of contact with air, and the breeze is practically of the same quality as the coke, is of much more value, and contains valuable fuel, if properly manipulated; means to accomplish this economically have been devised by the author; the following is a description :—

Briquetting of Coke Breeze, Etc.—For the purpose of reclaiming the enormous quantities of breeze, coke dust, anthracite dust, and similar material, the author spent some years in experimental work, and after several successful trials evolved the process for briquetting substances such as dry anthracite, or coke dust, without any binder beyond that contained by the small proportion of bituminous coal mixed with these substances to form the briquettes, producing a high-class smokeless fuel.

Disposal of Breeze (Briquetting).—In the manufacture of coke either by the Beehive oven, or by the by-product oven, breeze to a certain extent is unavoidably produced. That from the Beehive ovens is of less value than that from by-product ovens, as it often contains large quantities of ash, as already stated, produced by the combustion of the coal on the surface of the coke, inside the ovens; and since this process is carried on for a period extending from 36 to over 80 hours, a considerable quantity of coal is consumed, the ash of which is left upon the surface of the coke, together with what are called *blackheads*, which are cut off by the coke burner; and since the coke is drawn from the oven on to a bench with rakes or forks, it is broken; the small pieces are termed *breeze*. This breeze, in some districts containing the ash as above stated, was

considered useless as fuel, and was usually either thrown away, or given away, to form footpaths or ballast; in some cases the railway company was paid to take it away. On analysis it is often found to contain as much as 60 to 70 per cent. of good fuel, which by a process of washing could be economically recovered; but, being in a comminuted form, a great deal of it is absolutely worthless as fuel, in its raw state, but by briquetting a good cheap fuel can be manufactured from it. The material obtained from the manufacture of by-product coke being cleaner, would not require any preparation, except crushing the lumps down to a uniform size for briquetting.

There are several methods in operation for the manufacture of fuel by briquetting, with many diverse binders. The principal material used in the manufacture of "patent fuel" is pitch, and breeze could be treated with this material and good briquettes made. A description of the processes now in operation for this manufacture is outside the scope of this work, there being other valuable treatises published by Messrs. Charles Griffin & Co. giving full details of the various processes.

A new process, however, invented by the author for the manufacture of smokeless briquettes from breeze or anthracite duff, may be described here, as the process is one of carbonisation at a low temperature, and for a very short period; the temperature does not exceed 650° C., and the material is heated for the space of a few minutes only at this temperature.

Fig. 180 shows a vertical section of the apparatus, which consists of two chains of moulds, or rather half-moulds, which have a row of about half a dozen semi-moulds alongside of each other, fig. 183, forming one section of the chain; these are linked or jointed together to form an endless chain, as at *m*, *m*, fig. 180. These moulds are actuated by the rollers *k*, *k*, and as they pass along the upper part of the apparatus they are filled with a mixture of coke breeze, 80 per cent., and bituminous coal slack, 20 per cent., crushed fine, and filled into the hoppers, *b*, *b*, by means of a conveyer. The paddles, *g*, *g*, press the mixture, which is slightly damp, into the moulds as they pass under the hopper, and completely fill them; the slide *e*, *e*, cuts off the surplus and presses the material into the moulds. The two halves now charged are brought together at the point where the two rollers, *k*, *k*, actuate the chain; they are then automatically fastened or locked together by means of the device shown in fig. 181, where *y*, *y* show the ends of the moulds upon which are formed projecting cams; when the two half-moulds are brought together, the plain end of each alternate mould marked *o*, *o*, receives the projecting cam, which enters behind the posterior end of the cam on the previous mould, and thereby fixes the two moulds, both vertically and horizontally, until they have traversed the vertical heated flue, and arrived at the bottom rollers, *v*, *v*, where the cams are automatically released; the briquettes in the moulds being at a dark red heat, fall out automatically on to the travelling band, *x*, *x*.

The heating flue is formed in the brickwork of the apparatus, and is preferably heated by gas, but other means can also be used to accomplish the heating, such as electric contacts. When gas is used to heat the flues, generally coke-oven gas, it is conducted to the combustion flue by tubes, at *n*, *n*; the air for combustion enters the brickwork at u^1, u^1, traverses the flues *s*, and arrives at *n* in a heated state, where it meets the gas, which burns up the flues *p*, *p*; the exit to the chimney is at *r*, *r*. The small amount of gas given off during the low temperature carbonisation is collected into the flue from the moulds at *r*. The gas, and also the air, are under perfect control by means of cocks and valves as at *u*, *u*. The roller, *k*, on the left, is fixed by the adjustable set screw,

f, while the roller on the right is free, but subject to the pressure of the spring, *h*, which allows the moulds to pass without undue friction. The moulds, while they are being filled, slide along the plate *l*, which keeps them level, so that the replete filling is performed. The height of the vertical heating flue is usually 25 feet, and the time taken in the passage down this flue is about 20 minutes; during this time the material is heated to the requisite temperature; the

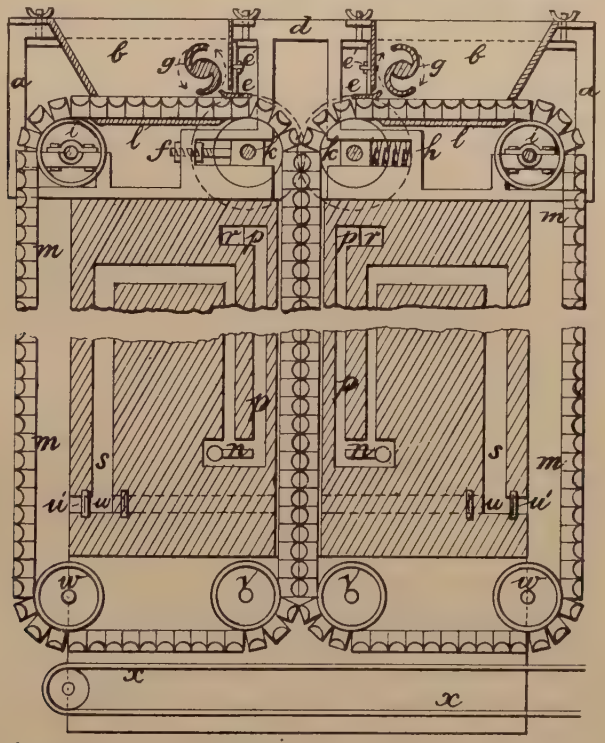


Fig. 180.

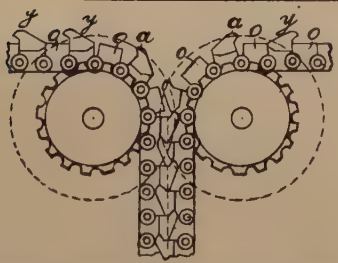


Fig. 181.

Fig. 180.—Vertical Section of "Armstrong" Briquette Apparatus and Furnace.
Fig. 181.—Locking Mould Mechanism. "Armstrong" Oven.

bituminous coal to the extent of 20 per cent. of the volume of the mixture of either dust breeze or dust anthracite is softened and coked; the volatile matter contained in the bituminous coal is eliminated during this 20 minutes, and leaves the briquettes perfectly dry, hard, and absolutely smokeless. The briquettes when finished have the appearance as if a great pressure had been

applied to them in their manufacture, whereas, as shown above, no pressure is used, but owing to the interior of the mould being closed, the bituminous coal swells by heating, thus filling the mould by its own internal expansion. A trial apparatus was erected by the author at the works of Messrs. Wm. Cory & Sons, at Erith, and a mixture of anthracite and bituminous coal in one case, and in the other coke breeze and some of the original coal slack used in the making of the coke from which the breeze was taken. These briquettes differ from all others by the fact that they are porous. Briquettes made by pressure, with a binder such as pitch, or other plastic material that acts as a cement, are usually very compact and solid, not very easily burned, and difficult to light beyond the flare caused by burning off the superficial tar; whereas, on the other hand, ordinary anthracite or coke, for the same reason, is difficult ta light or to burn, while the former has the disadvantage of being liable to decrepitation, that is, splintering or flaking off under heat, causing the grate at the bottom of the stove to be blocked. This process completely changes the character of both anthracite or hard coke; since it is reduced to powder previous to admixture with the bituminous coal, its proclivity for decrepitation is destroyed, and the solidarity preventing the due and rapid admission of air for combustion is also removed; the action of the bituminous coal in binding the particles of anthracite or coke together, in the formation of the briquettes, is to form small sponge-like bubbles in the interior, producing a porous briquette, easy to light, and easily burned in any kind of grate or stove; the briquettes burn right down without disintegration.

The following is an extract from a report upon these briquettes by Dr. Carrick Anderson, of Glasgow :—

ANALYSIS OF BRIQUETTES.

	Anthracite Briquettes.		Coke Breeze Briquettes.	
Carbon,	81·35	per cent.	74·45	per cent.
Hydrogen,	2·64	,,	1·29	,,
Oxygen and Nitrogen,	3·20	,,	10·17	,,
Moisture,	3·61	,,	2·68	,,
Ash,	9·20	,,	11·41	,,
	100·00	,,	100·00	,,
Calorific Value, calories,	7345	,,	6022	,,
Equivalent to British Thermal Units per pound,	13·223	,,	10·840	,,

Both sets of briquettes are clean, strong enough to stand a considerable amount of handling, and burn readily.

Figs. 182 and 183 are taken from photos of the apparatus, and shows clearly the chain of half-moulds as they enter the machine to be filled, and then are brought together and locked automatically, passed down the heated flue, automatically opened, and the finished briquettes discharged in less than 30 minutes.

THE PHYSICAL AND CHEMICAL PROPERTIES OF COKE.

The chief physical characteristics of coke are porosity and hardness, and these two properties depend upon a great number of circumstances obtaining during the formation of the coke and also on its composition. Coke made in the same oven from the same coal may differ widely in the physical properties of hardness and porosity; the hardness of some cokes is determined by the class of coal

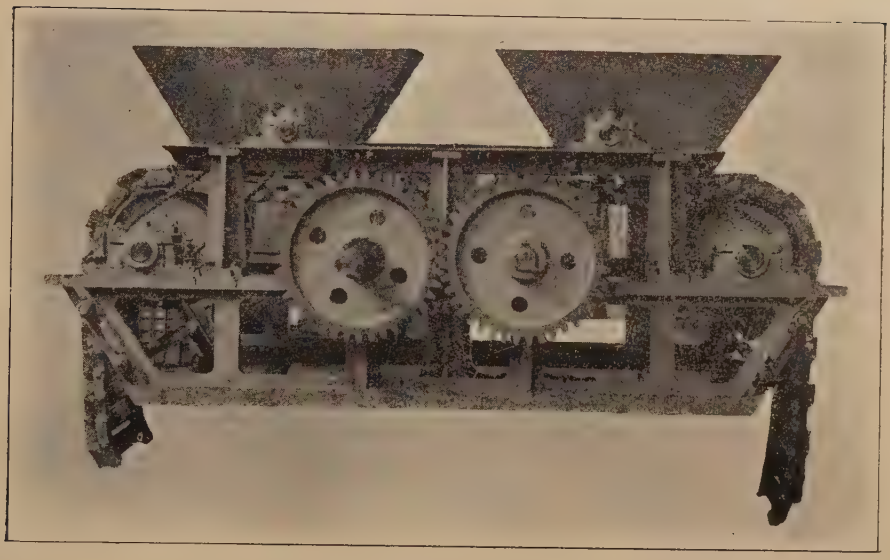


Fig. 182.
Side Elevation of "Armstrong" Briquetting Apparatus.

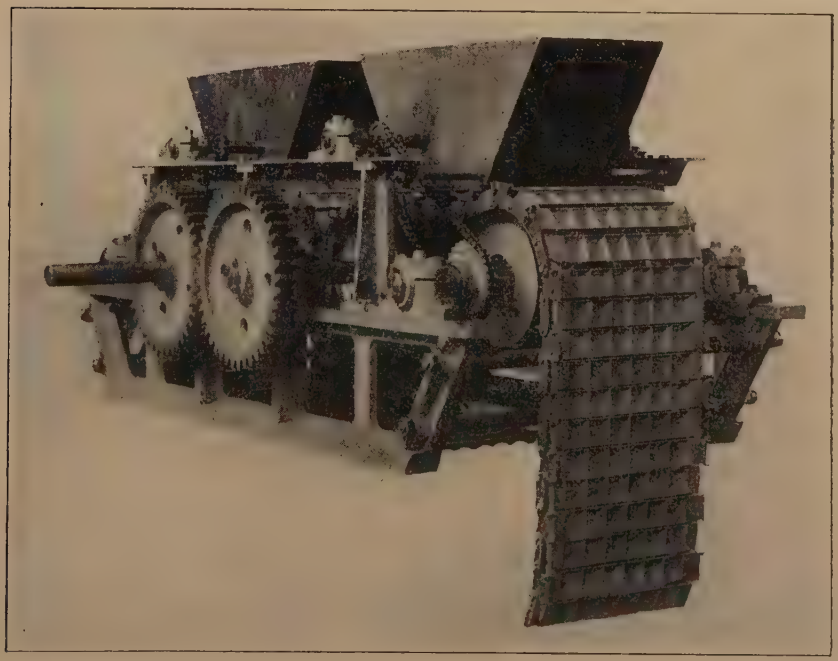


Fig. 183.
Figs. 182 and 183.—"Armstrong" Machines for making Briquettes..

from which they are made, and the amount of ash that they contain, as well as the amount of volatile constituents that are developed and expelled in the process of carbonisation; circumstances such as pressure and temperature during the coking period, have a decided influence in determining the character of the coke. The method of coking, the size and character of the oven, the length of the coking period, high or low temperature, uniform heating, the application of pressure or vacuum on the gas exit, all have a modifying influence on the character of the coke.

By the judicious control of some of the conditions enumerated above, inferior coke can be much improved, but good coke cannot be made from bad coal; the fundamental essentials of good hard coke is good clean coking coal, but even with such coal poor coke may be produced, due to the method of coking; low temperature carbonisation, or insufficient time even with high temperature, may produce it. The porosity of coke is determined by the gas that is given off during the carbonisation; a coke may possess large pores and strong pore walls, or it may have small pores and weak walls, or *vice versa*, and the size of the pores or gas cells are, as a rule, a considerable factor in determining the hardness of the coke; cokes with small pores and strong pore walls are the hardest; this class of coke is generally produced from a coking coal that completely melts during the critical period of heating, when the gas is given off freely, and thus makes its escape easily; if pressure is used during the period of coking, the cells or pores are squeezed after the gas has escaped, and the amorphous mass immediately consolidated, thus producing very fine and very small pores with strong cell wall structure. On the other hand, coal that does not sufficiently melt at the critical period of carbonisation generally forms large cells by reason of the gas extending the tough, doughy mass, which in the absence of pressure will form a loose, large-pored, and friable coke, and even with pressure applied, the difficulty of exit for the gas, which to a certain extent remains too long in the mass after the critical freezing or hardening period, results in cells which are not much altered in size, and remain comparatively large, but under certain circumstances may have strong walls.

The formation of cells or pores in the coke during carbonisation is continuous and progressive; as the heat penetrates the mass of coal, the coal in a very thin layer at right angles to the line of direction of the heat undergoes softening, complete melting, liquefaction, and almost immediate subsequent hardening; if the temperature is high this will proceed rapidly and produce small cells, and if the temperature is low, subsequent hardening will be slower and larger cells will be produced; thus high-temperature coke will possess small and close porosity, whilst low-temperature carbonisation will produce large and loose porosity from the same class of coal, other conditions being the same.

A high degree of comminution of the coal will also assist the process of carbonisation, and the production of small pores, while coal carbonised in large pieces will have larger pores, under the same conditions of temperature, etc.

Porosity is also very largely determined by resistance, that is, the coal coked against the walls of the oven will possess smaller pores or cells than that near the centre of the oven, and furthest from the walls; this is due to the fact that, while carbonisation commences near the heated walls of the oven, the pressure of the raw coal is greatest there, and the gas expelled from the critical region of fluidity of the molten coal will have to penetrate the mass of comparatively cold coal before it makes its exit; this the author proved by an experiment with a small iron mould about 3 inches in internal diameter, made

in two halves, into the interior of which he placed comminuted coking coal, and heated the whole, after firmly closing the two halves, until the contents were completely carbonised ; on opening the mould he found a piece of perfectly hard coke surrounding the sides, the process of carbonisation having proceeded from each heated side of the iron mould towards the centre ; but upon breaking the piece of coke, he found it was formed with a direct progression of cells or pores, those against the heated sides being small, while those in the centre were exceedingly large ; the coke was very hard and dense on the outside near the walls, but was very tender and friable in the interior, where the large cells were situated. There is no doubt that this state of affairs resulted from the gradually decreasing pressure, and the pushing forward into the colder region of uncoked coal, of the tarry matters ; so that when the heat had penetrated to the centre, and all the coal had become carbonised and consolidated behind the critical melting zone of progressive carbonisation, the tarry matters were last carbonised in large and friable bubbles, which formed a very spongy and feebly resistant coke. This obtains in all coking processes, more or less, and in the process designed by the author for the carbonisation of Lanarkshire coal (which cannot be coked in the ordinary horizontal by-product oven), and which is described in Chapter VIII. The heat from the walls of the verti-circular oven at a very high temperature, penetrating the mass of cold, comminuted coal causes the gas produced to meet with considerable resistance in making its exit, leaving behind its tarry matters ; and as the heat penetrates from the circumference to the centre, the liquid tarry matters are concentrated, so that the coke formed, from the bottom of the oven until about 3 feet from the top is very dense, and no appreciable difference can be observed in the degree of fineness of the cell structure, except near the top of the charge, where the coke is dense near the walls, but possesses larger cell structure near the centre for about 3 to 4 inches, but above this centre core there is a pyramid of coke sponge, as shown in fig. 45, formed no doubt by the carbonisation of the tarry matters, with pores or cells as large as $\frac{1}{8}$ to $\frac{3}{4}$ inch diameter ; this is found on the top of the centre of the charge in this oven, and is absolutely free from any pressure.

In testing the hardness of coke, much depends upon which way the pressure is applied in ascertaining it ; a coke that is produced under pressure with its pores flattened will not resist the same pressure on its sides as on its ends ; it is like a piece of wood, which will stand a higher crushing strain on its end than on its sides, because the pores are elongated, and their camber is less on the small Gothic arch shape of their ends than on the long camber of the very flat arch on their sides ; therefore, when tests are made of the crushing strength of a porous material like coke, the fact of the cell structure, and its shape, with regard to its perpendicular or horizontal axis must be taken into consideration.

Great care must also be taken, when giving statistics as to the resistance and hardness of coke, to be certain that there are no concealed cracks or fissures in the coke ; should such exist in any one of several samples of the same coke operated upon, the sample with this defect, even if it is undetectable, will upset all the calculations that may be made on the samples. The trials of hardness and resistance should be made, not only in the cold, but at the same temperature as the furnace where it has to be employed.

Coke intended for smelting purposes in blast furnaces should possess not only hardness, but hardness of cell wall structure, in order to resist attrition ; the defect of all coke used in blast furnace practice is friableness, and testing coke with pressure only may not completely determine its friability ; a surer

test would be to subject it to a rubbing test, at the same temperature as the furnace where it will be necessary for it to carry its burden without attrition. The necessity of obtaining coke with the necessary qualities for smelting iron in the blast furnace is now greater than ever, because the iron produced for the manufacture of steel has to be of such a quality and purity that the steel will pass the analytical tests required by the purchaser.

Coke, therefore, must not contain any deleterious matter, except in such quantities as will not influence the quality of the iron produced. The worst ingredients that are found in coke are sulphur and phosphorus; these have a detrimental effect on the iron, the metal absorbing them to a large extent, when present in the coke.

Numerous proposals have been put forward for de-sulphurising coke, but no practical economical process seems to have been adopted for this purpose. The best and safest plan is to secure coal free from these deleterious substances for the manufacture of the coke for smelting purposes; that containing a large proportion of these impurities may be made use of for other purposes without harm resulting.

The ash is also a matter for consideration in connection with the quality of coal used for making coke, as the ash does not produce any heat, and is a diluent, occupying space in the furnace; the less ash a coke contains the better, both from the point of view of economy and quality, as the ash content tends to depreciate the hardness of the coke, making it more friable.

Friability in blast-furnace coke acts deleteriously in two ways; firstly, it breaks up the large pieces that are required to keep their size and shape until they descend to the region where they are consumed, and, secondly, by producing an amount of dust that is not consumed, but is either blown out of the top of the furnace and carried away by the escaping gases, or falls into the hearth and gets entangled in the slag, or, as sometimes happens, this coke dust agglomerates in the hot region above the tuyères, and forms dense masses with half-reduced portions of the charge that the blast cannot penetrate, and thus deranges the normal operations of the furnace.

One of the serious losses of the process of iron smelting in the blast furnace is the premature oxidation of the coke in the charge; this is accounted for by the fact that generally the coke is in the form of large, round pieces, which, when charged into the furnace, roll down to the walls, and leave the smaller portion of the charge in the centre; the blast naturally finds its way to the top of the furnace by the line of least resistance, and this path is often up the sides of the walls of the furnace where the large coke is situated, there undergoing decomposition into CO_2 and CO gases; if these gases could be employed inside the furnace for useful work there would be no complaint, but they are often expelled from the furnace without any useful result having been obtained either in producing heat or in reducing the ore to metal. During the reaction in the upper parts of the furnace, the process is endothermic and heat is absorbed. In the past, with the open-mouthed furnace, this was the cause of enormous losses in fuel, but in modern practice it is to a large extent recovered in the gases, which are made use of where possible, but in most cases even yet the loss under this heading is very considerable, and is unavoidable under the present method of blast-furnace operations

This has often nothing whatever to do with the quality of the coke employed, but is entirely due to the method adopted in charging the furnace, which consists generally of feeding in the charge from the top as successive charges of coke, iron ore, and lime flux. The results attending

this method are satisfactory as regards the efficient working of the furnace and the regular daily production of its tonnage of pig iron, but it is done at the expenditure of a certain tonnage of coke, and if the coke is in any way soft, so that CO_2 gas may attack it in the upper part of the furnace, CO gas will be formed and escape, causing losses in fuel. Sir J. Lowthian Bell investigated this action of CO_2 on the several kinds of coke employed, and found the average of the analyses of several samples of gas taken from an 80-foot blast furnace, smelting calcined Cleveland ore and limestone with hard coke; the blast was heated to a temperature of about 485° C.; the exit gases from the top of the furnace had a temperature of about 332° C. Their average composition was found to be :—

Nitrogen,	60·93
Carbon Monoxide, CO,	26·62
Carbon Dioxide, CO_2,	11·75
Hydrogen,	0·70
	100·00

The gases from various other blast furnaces in different localities have been examined, using various kinds of fuel, including coke, charcoal, and coal.* The following mean analyses were obtained :—

Percentage by Volume.	1	2	3	4	5	6	7
Nitrogen, N_2,	62·34	57·22	55·62	56·64	55·35	54·91	52–60
Carbon Dioxide, CO_2,	8·77	12·01	12·59	11·39	7·77	18·36	3–8
Carbon Monoxide, CO,	24·20	24·65	25·24	28·93	25·97	26·66	25–30
Methane, CH_4,	3·36	0·93	..	..	3·75	..	..
Ethylene, C_2H_4,	..	..	..	..	0·43	..	2–4
Hydrogen, H_2,	1·33	5·19	6·55	3·04	6·73	0·07	5–7

The numbers 1, 2, 3, etc., refer to the following, in which the localities and some details of the process are given :—

1. Veckerhagen, Hessen Cassel; Bunsen; fuel :—charcoal.
2. Clerval, France; Ebelman; charge of brown hæmatite, limestone and charcoal.
3. Audincourt, France; Ebelman; charged with brown hæmatite, forge-cinder, limestone, wood, and charcoal.
4. Seraing, Belgium; Ebelman; charge :—brown hæmatite, mill-cinder, limestone and coke.
5. Alfreton, Derbyshire; Bunsen and Playfair; charge :—compound of calcined argillaceous ores, limestone, and raw coal.
6. Ormesby; smelting Cleveland ore with coke; temperature of blast, 1,507° F., furnace, 35,013 cubic feet capacity.
7. Average range of gases from Scotch blast furnaces fed with splint-coal.

Sir J. Lowthian Bell also made some comparisons between the coke made in Beehive ovens and that made in Simon-Carves ovens; he found that with regard to their calorific power there was not much difference, the ratio being 98·5 : 100, but the quantity of each that was required in the blast furnace to do similar work was, however, in the ratio of 91 : 100, this disparity being due to the fact that one coke was more easily attacked by CO_2 in the blast furnace than the other, so that the coke with the greater resisting power to CO_2 would be the most economical. The fact is that coke made in the Beehive

* "Elements of Metallurgy," Phillips and Bauerman, p. 256.

oven has an outside face which generally is smooth, and which is more impervious to CO_2 than coke with open pores; such coke will also have the power of passing down through the furnace without being impregnated with the molten, reduced metallic iron, whereas when the pores of the coke are open to such extent that the liquid iron is absorbed, when it comes down into the region of the tuyères, the coke is consumed by the oxidising blast, and the metallic iron contained in its pores is also oxidised, and either passes into the slag or requires a further quantity of carbon to reduce it again. This would seem to be a more serious question in the process of melting cast iron in the cupola furnace, where reduction does not take place, but any iron thus oxidised passes into the cinder, and is lost.

Beehive coke is, therefore, the best for foundry purposes for this reason, and being thus impervious to the molten metal, it also stands well against the blast and is more slowly consumed than the other; it is also in the foundry, where coke is required which is of a quality having the minimum of friability and the maximum of hardness, in order to bear the severe treatment generally served on it in the cupola melting furnace, where the pigs of iron are thrown into the furnace on to the top of the coke, their weight often falling directly on the latter.

An interesting table is given of some American cokes by Mr. Fulton, showing the strength, specific gravity, weight, hardness, number of cells, etc. :—*

Locality.	Weight in Lbs. of one Cu. ft.		Percentage.		Comparative Strength per sq. in.	Height of Charge it will support without crushing.	Hardness.	Specific Gravity.
	Dry.	Wet.	Coke.	Cells.				
Connelsville,	47·47	77·15	31·33	38·47	284	114	3·50	1·500
W. Virginia,	52·54	81·56	64·32	35·67	258	103	3·15	..
Broad Top, .	44·81	76·88	58·27	41·73	240	96	3·35	1·342
Clearfield, .	56·35	76·69	74·43	25·57	319	128	3·60	1·56
Cumberland,	48·61	82·41	58·99	41·04	215	86	3·00	1·750
Alabama, .	50·70	69·01	73·77	26·23	225	87	3·50	1·493
Illinois, .	42·02	65·09	63·79	36·21	180	70	3·20	1·215

The duration of the coking period is the chief factor in the production of hardness in a given coke; this is due probably to the continued heat of the evolution of hydrogen, and the concentration and condensation of the cell wall structure. According to Wedding, quoted by Anderson :—

70 hour coke from Beehive ovens at Connelsville stands a pressure of, ... 284 lbs. per square inch.
48 hour coke from Beehive ovens at Connelsville stands a pressure of, ... 249 „ „
24 hour coke from closed ovens at Johnstown stands a pressure of, ... 245 „ „

Anderson also quotes from the *Colliery Guardian* with regard to this American coke, of which in 1901 the output was 12,609,949 tons of the best quality. The proximate analysis is as follows :—†

* Fulton, *Trans. Amer. Inst. Mining Eng.*, vol. xii., p. 212.
† "Chemistry of Coke," Anderson, p. 136.

Coal.

Colliery.	Carbon.	Volatile Constituents.	Sulphur.	Ash.
Frick, ...	60·92	32·60	1·08	5·40
Trotter, . . .	63·34	30·20	1·06	5·40
Tip Top, . . .	60·90	32·10	1·40	5·60
Foundry, . . .	65·36	28·40	1·34	4·90

Coke.

	24-hour.	48-hour.	72-hour.	96-hour.
	Per cent.	Per cent.	Per cent.	Per cent.
Carbon, . . .	89·40	89·74	89·36	89·73
Volatile Constituents, .	0·64	0·60	0·53	0·53
Water, ...	0·03	0·35	0·04	0·03
Sulphur, . . .	0·68	0·67	0·88	0·64
Phosphorus, . . .	0·01	0·01	0·01	0·01
Ash, ...	9·23	8·94	9·18	9·06

The ash content of coke will materially lower its hardness, just as a diluent will do in any cement, provided the former is of a neutral character. In cokes there are few materials entering into their composition that will assist binding during carbonisation; iron, however, if in contact with silica, would perhaps be thought by some people to have a hardening effect on coke, due to the fact that iron and silica make a very fusible glass, but the iron must combine with the silica in its oxidised form, and at the heat of the coke oven and in the presence of so much carbon and reducing gas this can hardly occur. Coal, therefore, containing a large quantity of ash, such as silica or alumina or other earthy or mineral matter, will make the coke poorer and less hard and more friable as the proportion of the ash rises, and especially the quantity and proportion of silica.

Coke consists mainly of carbon, hydrogen, oxygen, sulphur, nitrogen, and the elements composing the ash present.

The carbonisation of coal in the manufacture of coke is never absolutely complete; there is always a remnant of hydrogen and oxygen, which even after coking for 96 hours is left in the coke. Differences of opinion among writers on this subject exist regarding the state in which these gases exist in the coke; some authorities, such as Parry, hold to the theory that the gases are occluded by the pores; on the other hand, Muck maintains that the elements are there in the form of solid carbon compounds, and gives for example the composition of "coke hairs," which consist, according to B. Platz, of—

95·729 per cent. Carbon,
0·384 „ Hydrogen,
3·887 „ Oxygen,

0·815 per cent. surplus oxygen over that required. These coke hairs have no pores or cells, so that the hydrogen and oxygen found in them are not occluded,

and this, therefore, points to the assumption of Muck that they are really present as solid carbon compounds, which are to a certain extent stable at high temperatures, since it is found that by long exposure to a high temperature these gases are evolved; probably they are in a state of chemical combination and somewhat difficult to dissociate except by prolonged heating, and it is difficult to say how the surplus oxygen is held as stated above other than as CO or CO_2; the hydrogen may be held as hydrocarbons where the chemical combination may be somewhat different from the hydrocarbons that have been already evolved in the process of carbonisation; even these hydrocarbons differ in their capacity of passing from one combination to another, as exemplified in the fractional distillation of tar, where the paraffin series of hydrocarbons are set free at a much lower temperature than those of the benzene series. Therefore, the hydrogen contained and remaining in the coke may be in some form of hydrocarbon requiring a very high temperature to effect its separation. The oxygen may be also held in a form of combination with carbon that also requires a high temperature to separate it.

Water in Coke.—Coke is not very hygroscopic, and absolutely dry coke exposed to a moist atmosphere, even to saturation, will not absorb more than about 1 to 2·5 per cent. of water, according to M. de Marsilly. The power of absorbing water depends to a certain extent upon the density of the coke and the size of the pores, and the internal fractures or fissures. Coke, however, when immersed in water, will take up a large quantity of water; in a series of experiments conducted by M. de Marsilly, he found that the average amount of water absorbed was 36·25 per cent., but in one case it amounted to as much as 51 per cent. after immersion for 24 hours. He states that previous to immersion the cokes were dried between 100° and 200° C. and weighed, and after immersion were taken out of the water, drained, and weighed again.

Coke that is quenched at the oven during the day is said to contain less water than that quenched at night, owing to the fact that the red glow can be seen at a lower temperature at night than through the day; the coke burner, therefore, applies more water to extinguish the coke at night, judging the condition by the colour of the coke; but as the coke is hot, and where the water thrown on to it is not excessive this generally evaporates, and when sent from the ovens to the market the coke should not contain more than 4 per cent. moisture. Excessive moisture in coke is a matter of no inconsiderable importance, since the coke is sold by weight; the water contained in it is, therefore, paid for, and becomes a serious loss when the fact is taken into consideration that the amount of weight of water is not the only factor in the loss incurred, but that when the coke is used in the furnace, the water has to be evaporated, using up fuel in so doing, with a lowering of the temperature during the process, the heat that is used becoming latent. Strict attention is, therefore, necessary to see that the proper amount of water is used in quenching, and that subsequently the coke is kept in a dry place until used.

Nitrogen.—The fact that coal containing a large percentage of nitrogen also contains oxygen goes to show that atmospheric decomposition has probably been the source of the nitrogen which has become fixed in the coal, and separated out from the oxygen; but, on the other hand, one source of nitrogen found in coal is the remains of animals and fishes that have been buried with the carbonaceous material forming the coal measures. It has been ascertained that this fixed nitrogen ranges from 0·4 to 2·57 per cent.

Coal from Northumberland (West Hartley)	. .	contains 0·96 to 2·24	per cent.	nitrogen.
„ „ Derbyshire	. .	„ 1·04 „ 1·42	„	„
„ „ Durham,	. . .	„ 0·67 „ 1·70	„	„
„ „ Gloucester,	. .	„ 0·47 „ 2·2	„	„
„ „ Lancashire,	. .	„ 1·86 „ 1·93	„	„
„ „ Leicester,	. . .	„ 1·22 „ 1·35	„	„
„ „ Monmouth,	. .	„ 0·60 „ 1·61	„	„
„ „ Nottingham,	. .	„ 0·49 „ 1·71	„	„
„ „ Staffordshire,	. .	„ 1·15 „ 1·323	„	„
„ „ Yorkshire,	. .	„ 0·75 „ 2·10	„	„
„ „ Scotland (Longrigg),	.	„ 0·76 „ 2·57	„	„
„ „ Wales,	. . .	„ 0·70 „ 1·54	„	„
„ „ Ireland,	. . .	„ 1·55	„	„

Although, as shown above, these large nitrogen contents in coal are never wholly separated from the carbon, and seem only to be expelled completely on the entire combustion of the coke, the amount recovered as ammonia in the carbonisation process very seldom, if ever, exceeds 50 per cent. of that present in the coal; nitrogen seems to have a great affinity for carbon, and, according to Watson Smith,* who made some investigations on three samples of coke, and found :—

Gas Retort Coke .	contains 1·375	per cent.	Nitrogen.
Beehive Oven Coke .	„ ·511	„	„
Simon-Carves Oven Coke	„ ·384	„	„

Dr. W. Carrick Anderson and J. Roberts made some very exhaustive researches into this question, and formed the opinion that the conclusions of Foster and Knublauch were substantiated, and that the nitrogen to a very large extent remains in the coke in the form of fixed compounds. Their results are shown in the following table, and were arrived at by heating 2 grams of finely powdered coal in a closed platinum crucible for two minutes over a Bunsen burner, and then afterwards for three minutes over a blow-pipe :—

Name of Coal.†	Nitrogen in coal, per cent.	Weight of fixed residue (coke), per cent.	Nitrogen in the residue, per cent.	Nitrogen expelled from 100 grams coal.	Nitrogen left in coke from 100 grams coal.	Percentage of original Nitrogen left in the residue or coke.
Lanarkshire, Ell coal, .	1·53	55·37	1·83	0·517	1·013	66·2
„ Splint, . .	1·50	55·14	1·73	0·527	0·973	64·9
„ Kiltongue, .	1·65	55·84	1·77	0·661	0·989	59·9
Stirlingshire, Bannockburn Main, .	1·89	69·93	1·80	0·631	1·269	66·6
„ Kilsyth, .	2·04	66·59	1·79	0·849	1·191	58·4
„ Lower Drumgray,	2·12	79·14	1·79	0·693	1·427	67·3

Anderson further states that the permanent percentage of nitrogen that remains in coke is very remarkable, and also states the fact that two samples containing 2·19 and 2·10 per cent. respectively, and exposed to a prolonged high temperature assayed after six hours 2·14 and 2·18 per cent.; but the nitrogen is converted into ammonia by means of hydrogen, as was proved by exposing one of the above samples during six hours at red-heat to a current of dry hydrogen gas, when it lost 17·27 per cent. of the nitrogen.

* *Journal Chem. Soc.*, 1884, p. 144. † "Chemistry of Coke," Anderson, p. 98.

All coals showing upon analysis nitrogen in their composition are not capable of giving this up as ammonia on carbonisation, nor any part of it; the nitrogen that is given off in the gases during carbonisation of this kind of coal remains unchanged as fixed nitrogen, and care should be taken to ascertain experimentally upon a given coal with nitrogen content, before installing expensive plant for the recovery of ammonia, that the nitrogen evolved is not that described above as fixed nitrogen, and that during the process of carbonisation ammonia will be produced.

Ash.—The ash in coke consists of the non-volatile constituents of the coal, apart from the carbon, which remain after the carbon has been consumed.

Carbonisation does not reduce the ash content in the coal, but, on the contrary, the percentage of ash found in the coal will be accentuated in the coke, because the volatile matter that has been evolved during the process of carbonisation does not carry with it any of the ash, or at any rate only a very small amount.

The presence of ash in coke is always to be avoided where possible, but so little coal is found with the requisite freedom from ash that great pains are now taken in preparing the coal, previous to carbonisation, to reduce the ash content to the smallest possible quantity. Ash does not only dilute the carbon of the coke acting as a heat producer or a reducing factor in the blast furnace, but may contain ingredients that are positively harmful, such as sulphur and phosphorus. The ash content of a given coal may be on the weight of the coal comparatively small; for example, five per cent. of ash would not be regarded as excessive in a good coking coal, but in some coals otherwise very pure and free from sulphur and phosphorus, but with a volatile content of 50 per cent., the ash content in the coke will be brought up to over 8 per cent. Again, the ash content in a coking coal may be only 2 per cent., but if the ash is made up of large quantities of sulphur and phosphorus, and the volatile matter is only about 33 per cent., the sulphur and phosphorus and the ash will be increased about 33 per cent. in the coke.

Good coking coal should, therefore, be mixed where possible for the purpose of adjusting the ash content, after all other methods have been exhausted for cleaning the coal; by the method of mixing coal thus, a very good class of coke has been secured, which otherwise was impossible from the coal used alone.

As ironmasters purchase coke for the purpose of smelting their iron ore, they require the carbon content of the coke for this purpose; any other matter that may be present in the coke in the form of ash is, therefore, useless in the process, and even worse than useless, since it takes up space in the furnace that should otherwise be occupied with substances doing active work; they, therefore, demand a coke with low ash content, and anything over 8 or 9 per cent. is looked upon with disfavour.

The ash is generally made up of silica, alumina, magnesia, iron, metal oxides, sulphur, etc. The ash in coal to a certain extent is mixed with the coal, but when the coal is got from comparatively thin seams, the roof and floor have to be cut away by the miner to make room for working, and a considerable quantity of either roof or floor often finds its way to the coke ovens, adhering to the coal which is not cleaned off by the processes of washing, and the ash from this source will contain silica, alumina, lime, magnesia, and iron. Percy gives the following analyses of the bed and roof and the intervening coal as mined from a bed of coal at Newcastle (Buddle's Hartley and Blaydon Burn Colliery) :—*

* Percy, "Metallurgy," Fuel, p. 278.

TABLE SHOWING THE COMPOSITION OF THE INORGANIC MATTER FROM BED AND ROOF OF A COAL SEAM AND OF THE ASH OF THE INTERVENING COAL.

Constituents per cent.	I.	II.	III.	IV.	V.
Silica,	62·44	59·56	64·21	56·51	58·99
Alumina,	31·22	12·19	28·78	31·89	26·19
Sesquioxide of iron,	2·26	15·96	2·27	..	5·14
Protoxide of iron,	..	..	..	7·04	5·11
Lime,	0·75	9·99	1·34	1·69	0·67
Magnesia,	0·85	1·13	1·12	0·85	1·54
Potash,	2·48	1·17	2·28	1·38	2·34
Soda,	..	..	..	0·61	..
TOTAL,	100·00	100·00	100·00	99·97	99·98

I. Fire clay, from the floor on which the coal seam rests, after subtraction of 10·5 per cent. of water and 0·44 per cent. of chloride of sodium and sodium sulphate.
II. Ashes (1·36 per cent.) of good coal after subtraction of 8·2 per cent. of sulphuric acid.
III. Ashes (16·9 per cent.) of coarse coal, after subtraction of the sulphuric acid.
IV. Bituminous shale, after subtraction of 39·35 per cent. of organic matter.
V. Bluish Shale, after subtraction of 11 per cent. of water.

He goes on to show also that shale is often inextricably mixed up with the coal, and the following analysis of a mixture from a black shale from High Delf Colliery, Gloucestershire, was made by C. Tookey in his laboratory :—

COMPOSITION, PER CENT., OF BLACK SHALE.

		Exclusive of Sulphur, Ash, and Water.
Carbon,	51·61	83·58
Hydrogen,	3·27	5·29
Oxygen and Nitrogen,	6·87	11·13
Sulphur,	2·60	..
Ash,	31·40	..
Water,	4·25	..
	100·00	100·00

Sulphur.—The presence of sulphur in coal is always undesirable; it may be in combination with iron in the form of pyrites, or in combination with lime in the form of gypsum, or it may exist as "organic" sulphur, derived from the plants or other organic bodies that originally formed the coal.

The process of carbonisation does to a certain extent eliminate a small amount of the sulphur that is in the coal; but part is retained in the coke, part is carried away with the volatile constituents and is found in the gas and tar.

When sulphur is present in the coal as iron pyrites, a large proportion of this can be washed out in the preparatory stage, before carbonisation, as the pyrites, being heavy, is separated by the hydraulic process; but, in spite of this, a considerable quantity remains in the coal, no doubt as minute particles that float away with the coal, or adhere to larger pieces of coal.

Anderson is of the opinion that 50 per cent. of the inorganic sulphur in coal may be eliminated during the carbonisation, but that the organic sulphur remains afterwards in the coke. It is also never possible to produce a clean coke free from sulphur if such a coke contains iron, lime, or magnesia in any quantity in the ash, as sulphur has a great affinity for these bodies, especially iron. Some of the sulphur can be eliminated by skilful coking and adjustment of the heat

of the ovens, but not to a sufficient extent to be of great service when the coal contains a large percentage of sulphur. A certain amount is also expelled from the coke during quenching, passing off as sulphuretted hydrogen, but this is very often deceptive, as a very little sulphur may make its presence felt in the steam from the hot coke, and it can only come from the surface of the coke, as the water cannot penetrate into the cell-wall structure of the coke. The fact remains that de-sulphurisation of coke by means of steam has proved to be uneconomical and inefficient, by reason of the action of steam on the incandescent carbon producing the reaction $H_2O + C = CO + H_2$, whereby the coke is diminished, without the desired result of the complete elimination of the sulphur.

Coke that is proposed for blast furnace use should not contain sulphur, except in small quantities; coke containing large amounts of sulphur will make the iron produced by it white and brittle. If the coke is to be used for melting iron in the cupola for foundry purposes, it may contain sulphur in much greater quantity than when used for smelting iron in the blast furnace, as a great deal of the sulphur is expelled with the products of combustion of the coke, and does not enter into the iron; that portion which may enter the foundry iron may be of service in counteracting the graphitic carbon that may be present in the iron, and which is a very undesirable ingredient of cast iron.

With regard to the influence of sulphur from the coke used in the blast furnace on the iron, the coke in the zone of combustion near the tuyères is wholly consumed, part of it giving the heat of the furnace and another part forming the CO gas of reduction which ascends into the zone of carburisation, taking along with it the liberated sulphur in the form of sulphurous acid; this acid attacks the lime and iron and other metals in the furnace, forming metallic sulphides, those of calcium and iron predominating; where the temperature is high enough, probably a certain quantity of carbon disulphide will be formed, which in contact with lime forms calcium sulphide, according to the equation $2CaO + CS_2 = 2CaS + CO_2$. Calcium sulphide will go into the slag, while the iron sulphide to a large extent will remain with the metal, and may be subsequently oxidised near the tuyères, and decomposed by contact with the highly carbonised iron, liberating the sulphurous acid, which passes up into the higher regions of the furnace, where it will form calcium sulphide with lime. There is no doubt that the presence of sulphur in the coke produces losses of iron in the blast furnace; O. Simmersback estimates that, on the yield of iron from a furnace with a daily output of 80 tons, using coke with 1·5 per cent. sulphur against a coke with only 1·00 per cent. sulphur, the annual loss would be £390.

Coke containing sulphur, after exposure to air and damp, shows brown spots, with a ring of various colours often around them; it is probable that these spots have been the residence during the coking period of grains of iron pyrites, which became enclosed in the coke; the iron becoming oxidised, forms the brown colour, having been reduced from the sulphide to the metallic state during carbonisation.

The de-sulphurisation of coke has been attempted by various methods, but none of them can be called a success; as has been already stated in this treatise, the only possible way of procuring coke low in sulphur is to select the coals carefully in the first instance, and with due preparation by washing and other preliminary processes for the elimination of the ash content, a generally good coke is now made at several establishments, fitted for use in the blast furnace and for other purposes.

The following is a list of coking coals showing the amounts of sulphur and ash:

LIST OF COKING COALS, SHOWING THE COKE, SULPHUR, AND ASH CONTENT.

BRITISH.

Locality.	Carbon Content. Per cent.	Coke. Per cent.	Sulphur. Per cent.	Ash. Per cent.
Durham and Northumberland,	..	66·70 to 72·19	..	..
„ „ South Peareth,	81·41	„	0·74	2·07
„ „ Bowden Close,	84·92	„	0·65	2·28
„ „ Willington,	86·81	„	0·88	1·08
„ „ Garesfield,	86·9	„	..	2·5
„ „ Hamsteels,	92·55	60·65	0·81	6·36
„ „ Consett,	91·88	„	0·84	6·91
„ „ Whitworth,	91·56	„	1·21	6·69
„ „ South Branspeth,	93·41	„	0·91	5·30
Yorkshire, Wombwell Main,	80·500	63·130	1·833	4·100
„ Darefield Main,	81·390	63·188	2·100	2·063
„ Oaks,	82·520	65·520	1·144	2·276
„ Elescar,	81·300	62·000	1·210	2·200
„ Masbro Park,	82·190	63·640	1·537	1·226
„ Edmunds Main,	82·190	63·280	1·447	1·312
Cumberland, Allerdale,	..	67·81	0·54	3·90
„ Little Main,	..	63·04	0·96	3·60
„ Harrington,	..	62·57	0·56	3·00
„ Brayton,	..	56·81	0·44	4·40
„ Whitehaven,	62·96	..	0·64	1·46
Derbyshire, Chesterfield,	..	58·04	0·24	3·59
„ Dronfield,	..	63·0	..	2·54
Gloucester, Crump Meadow,	77·72	67·50	2·23	4·55
„ Trenchard,	79·09	..	2·17	5·40
„ Coleford, High Delf,	..	59·60	0·82	3·07
Lancashire, Bispham Wigan Hall,	..	71·47	..	3·70
„ Chorley,	..	60·31	0·17	6·40
„ „	..	63·38	..	3·10
„ Burnley,	..	71·67	0·41	1·14
„ Accrington,	..	70·41	0·325	5·900
„ Wigan,	..	72·20	1·183	2·32
„ Rishton,	..	73·73	0·180	3·24
Monmouth, Elled,	..	68·00	1·77	4·52
„ Argoed,	64·47	67·50	1·42	3·03
Nottingham, Stanton,	..	57·63	0·18	1·55
Somersetshire, Greyfield,	..	60·26	1·53	7·50
„ Camerton, Bath,	..	65·31	0·95	3·82
„ Linsbury,	..	75·10	1·22	4·72
Scotland, Dumfriesshire,	..	56·95	0·16	2·51
„ Niddrie,	..	47·98	0·27	2·41
„ Fifeshire,	..	72·09	0·20	7·60
„ Drumgray and Kiltongue,	..	64·30	..	5·86
„ Drumgray,	..	56·35	0·34	1·90
„ Netherburn (Coking dross),	..	73·346	0·99	9·40
„ Hirstrigg Silkstone,	64·38	70·97	0·65	5·94
„ Glenclelland,	52·70	56·29	0·21	3·38
„ Bannockburn,	60·86	64·15	0·21	3·08
„ Banknock (Gas Splint),	55·73	59·54	0·23	3·58
„ Banknock (Coking),	56·41	60·20	0·17	3·62
„ Plean,	70·52	72·25	0·14	1·59
Wales, Wrexham,	57·25	59·70	1·34	2·45
„ Ruabon,	60·17	62·61	0·18	2·26
„ Flintshire,	60·705	..	0·623	3·920
„ Great Western Colliery,	93·234	..	0·774	5·970
„ Ffaldaw,	94·317	..	0·691	4·976

List of Coking Coals, Etc.—*Continued.*

Foreign.

Locality.	Carbon Content. Per cent.	Coke. Per cent.	Sulphur. Per cent.	Ash. Per cent.
Épinae,	81·12	63·60	..	2·53
Rive-de-Gier,	87·45	68·00	..	1·78
Alais, dep. du Gard,	89·27	78·00	..	1·41
Céral, dep. de l'Aveyron,	75·38	58·40	..	10·86
Mons,	85·10	72·90	..	2·16
Hungary,	86·93	78·85	0·86	0·89
,,	69·59	77·81	5·53	11·41
,,	79·63	81·55	0·90	10·33
Germany, Saar,	86·400	..	8·540	
,, Westphalia,	85·00	..	6·400	
,, ,,	91·77	..	6·933	
Australia, N. S. Wales,	88·086	..	0·594	10·456
,, ,,	90·880	..	0·420	7·930
,, ,,	84·210	..	0·508	14·050
America, Connelsville, Pa.,	89·576	..	0·821	9·113
,, ,,	89·150	..	1·200	9·650
,, West Virginia,	93·850	..	0·300	5·850
,, Ohio,	93·750	..	0·879	5·380
,, ,,	90·630	..	0·270	8·380
,, Tennessee (Tracy City),	83·364	..	0·142	15·440
,, ,, (Whitesides),	94·560	..	0·790	4·650
,, Alabama (Warrior Field),	88·224	..	0·563	11·315
,, ,, (Cahaba Field),	84·035	..	0·445	15·216
,, Illinois (Big Muddy),	88·180	..	0·010	10·070
Japan, Takashima,	79·26	58·01	0·11	4·51

Iron.—Iron is found in coal in various quantities from mere traces up to a general mixture of coal and iron ore; generally the small quantity present may be there as pyrites, or may be carbonate, having been disseminated throughout the deposit from the decomposition of the organic remains of the vegetation that composed the coal measures.

Iron in coal or coke, for purposes other than the smelting of iron in the furnace, is undesirable, on account of the fluxing nature of iron with silica and other substances composing the ash, producing fusible clinkers, which give a great deal of trouble in removal from the fire; this material, when it runs together in the fire, binds up the waste ash with considerable portions of unconsumed carbon, which, when the firebars are cleaned, are removed and lost with the waste clinkers. Fusible ash containing silica, lime, iron, and alkali, not only forms clinkers which are troublesome and difficult to remove without loss of fuel, but this fusible material rapidly fluxes away the brickwork forming the sides of the fireplace. The destructive influence of this kind of ash in coal or coke is perhaps more apparent with coke from gas-making plant, on account of the nature of the coal employed in the manufacture of the coke, gas being the chief object of manufacture; the ash content in the coke, containing iron, alkali, and silica, is, therefore, as a rule, higher than in coke made for furnace purposes; fire grates fed with the latter kind of coke generally last longer without repairs than when using coke containing fluxing clinker in the ash.

Iron, when an ingredient in the coal or coke used in the blast furnace, is reduced, and becomes metal. Anderson states that, "the quantity of iron in coke is generally in inverse ratio to the alumina present in the ash," and he gives a list of German cokes that contain from 0·5 to 1·4 per cent. of Fe, with a mean of 0·90 per cent. Fe; also a series from the Ruhr with a content of Fe from 0·722 to 1·590 per cent.*

Phosphorus.—The amount of phosphorus found in coal and coke is very variable, and never very large. German coal shows about 0·01 to 0·03 per cent. American coal, an average of 0·01 per cent.; some coals contain a little more, up to 0·033 per cent. and below 0·01 per cent. British coal is also as variable as those above quoted. There are many coals and cokes that are quite free from phosphorus. This ingredient seems to have originated from the organic remains that composed the coal deposits, and when coal containing phosphorus is carbonised, phosphorus does not readily volatilise like sulphur, but, on the contrary, it finds its way entirely into the coke, and when this class of coke is used in the blast furnace and is there completely oxidised and consumed, the phosphorus finds its way into the metallic iron, except a small quantity that may be fluxed away in the slag or perhaps be carried away in the gases. Its influence upon the iron is to make it harder and less tenacious, and thus injures it for the subsequent processes which it has to undergo in rolling, etc., but for making castings in the foundry it seems to help the founder by causing the iron to flow more freely.

Silica.—Silica is found in coal and coke, and is a constituent that is scarcely to be avoided, being so universally distributed, and so often finely divided that it may be carried by wind or water into the coal measures as they are laid down. It is a substance that forms a not inconsiderable part of the matter removed from the coal during the preliminary process of washing and jigging, previous to coking. Its content should be as low as possible in coke for any purpose, as it is not combustible, and where there is iron present in sufficient quantity it tends to produce hard clinkers in the grate. Silica also tends to render coke friable when in large quantity; it detracts from the hardness by destroying the resistance of the cell walls to pressure, and this weakness increases as the quantity of silica increases.

Other substances enter coke as impurities, but are often in very small quantities; such are lime, magnesia, oxides of zinc, arsenic, lead, etc.; some of these may be detected by the white or yellowish incrustations that are to be found on parts of the furnace, when the coke containing these substances is burned.

* Anderson, "Chemistry of Coke," pp. 115 and 116.

CHAPTER XI.

COAL CARBONISATION BY-PRODUCTS.

Gas, Tar, Ammonia, Benzol.

A by-product is that which is produced as a residue, or as a necessary side-issue, in a manufacturing process. In the destructive distillation of coal for the purpose of manufacturing metallurgical coke, the by-products are gas, tar, ammonia, benzol, and the derivatives of these resulting from subsequent processes. In the manufacture of illuminating gas, on the other hand, gas is the main product, whilst coke, tar, ammonia, and benzol are the by-products.

In the destructive distillation of coal, whether for the manufacture of metallurgical coke, or for the production of illuminating or heating gas, the whole If the by-products produced are very valuable, and often are a source of greater revenue than the primary product. It is fortunate that this is so in modern practice (it was not always thus, by-products in the early days of coal carbonisation were a drug on the market), otherwise the production of metallurgical coke or illuminating gas would have to be carried on at a loss, or their cost would have to be so great as to curtail their use to a large extent. On the contrary now, the cost of production of either the one or the other is often completely defrayed by the sale of the by-products and the materials that can be produced from them. This state of affairs has in recent years given such a recompense to manufacturers of both coke and gas that they have extended their operations beyond the mere production of either main product, and have laid down extensive plant for dealing with the by-products, and in many instances carry their development of the products obtainable from coal tar into other and quite distinct businesses. This is exemplified by the products produced from the coal-carbonisation industry, these forming a branch of chemistry of the utmost importance in modern industry. The scope of this work does not allow that these processes should be followed into their technical details, but there are certain preliminary stages in the processes which are now part of the work carried on in connection with the production of coke and gas, and which, therefore, form a subject to be treated here, as it is necessarily bound up with the process of carbonisation, where the by-products are saved. Tar, ammonia, and benzol are the three important by-products—if they can in modern practice be called by-products, their manufacture being at present just as much that of a primary product as coke and gas.

Coal Tar.

Tar is the most important by-product from the carbonisation of coal or wood, and is evolved with the gas; the latter is generally saturated with it, in an extremely fine state of division. It is very variable in its constitution, according to the circumstances under which it is produced, whether at a low or high temperature, and whether from wood or coal, or different kinds of coal. Thus the tar produced from the distillation of wood at a high temperature will be

black, and be both in appearance and smell very like that produced from coal; it contains phenol, benzene, toluene, and naphthalene; that obtained from wood at a low temperature will contain cresol and guaiacol instead of phenol, and the paraffins instead of the naphthalene series, and is very much lighter in colour, being brown instead of black.

The same may be said of tar from the destructive distillation of coal, the temperature at which the distillation is carried on is the chief factor in producing the different results. Low temperature carbonisation of coal produces tars containing the paraffin series, whilst in high temperature carbonisations the tars contain practically none of the paraffin series, but compounds much richer in carbon, with more hydrogenised products, while at very high temperatures the free carbon is separated, and if the temperature is pushed to extremes, complete dissociation will occur, with free carbon on the one hand and free hydrogen on the other; but this never takes place in ordinary practice, either in gas works or at coke ovens. The tar produced at gas works, and at coke ovens, in modern practice, is very different from the tar that was produced in the early days of coal distillation for gas-making, using iron retorts, and for this same reason, that the temperature in the iron retorts was very much lower than is now maintained in the fireclay retorts, or in the coke ovens. The tar is also produced in less quantity the higher the temperature of carbonisation. The temperature at which the iron retorts were worked was generally about 800° C., and never approached 1,100° C., the temperature at which the fireclay retorts are generally worked at present.

L. T. Wright (*Journal Soc. Chem. Ind.*, 1886, p. 559), quoted by Lunge, states that as the distillation temperature is raised the tar decreases slightly in quantity, but increases in specific gravity; and above a certain temperature, which differs for each kind of coal, the trouble caused by thick tar stopping up the pipes, etc., prevents the gas-making process from being carried on. In the average gas works the distillation temperature is as high as can be conveniently attained with the present form of gas-making plant, so that there is practically no margin for any reduction in the output of tar by the employment of greater heats. The following table illustrates the variation in the volume and weight of tar and gas produced from coal carbonised at different temperatures :—

Description of coal.	Temperature of Distillation.	Cubic feet of Gas per Ton.	Gallons of Tar per Ton.	Specific Gravity of Tar.	Tar per Ton. Lbs.	Weight per cent. on Coals.
Derbyshire Black Shale, No. 1, . . .	Very high.	11,128	10·63	1·210	128·62	5·74
Do., Do., .	Normal.	10,400	..	1·185	..	..
Do., Do., .	Very low.	7,856	11·50	1·145	131·67	5·88
Derbyshire Black Shale, No. 2, . . .	Very high.	11,190	12·01	1·207	144·96	6·47
Do., Do., .	Normal.	10,400	..	1·185	..	..
Do., Do., .	Very low.	7,562	14·38	1·136	163·35	7·29
Notts Top Hard Cannel,	Normal.	9,852	21·32	1·147	244·54	10·92
Do., Do., .	Very low.	7,125	23·81	1·116	265·72	11·85

This same writer in 1888 examined the tar produced from the same coals at different temperatures ranging between 600° C. and 800° C. The coal gave C = 81·92 per cent., H = 5·39 per cent., N = 1·28 per cent., S = 1·97 per

cent., O = 6·88 per cent., and ashes = 2·56 per cent. The following table shows the different amounts of the constituents in the tar at five different temperatures of distillation :—

	I.	II.	III.	IV.	V.
Cubic feet of Gas yielded per Ton of Coal, . .	6,600	7,200	8,900	10,162	11,700
Specific Gravity of Tar, .	1·086	1·102	1·140	1·154	1·206
Composition of Tar per cent.					
Ammoniacal Liquor, .	1·20	1·03	1·04	1·05	0·383
Crude Naphtha, . .	9·17	9·65	3·73	3·45	0·995
Light Oil, . . .	10·50	7·46	4·47	2·59	0·567
Creosote Oil, . . .	26·45	25·83	27·29	27·33	19·440
Anthracene Oil, . .	20·32	15·57	18·13	13·77	12·280
Pitch, ...	28·89	36·80	41·80	47·67	64·080

These results are surprising in that with rise in temperature of distillation the yield of naphtha sinks, and the light oil also, the combined drop being from 19·67 to 1·562. The ammoniacal liquor diminishes from 1·20 to 0·383, while the pitch rises from 28·89 to 64·080. It is due to this fact that the tar distiller prefers tar produced at a low temperature, as being easier to manipulate.

The difference in the quality of the coal has a great influence upon the constituents of the tar. Northumberland coals furnish a tar rich in naphthalene and anthracene, while some of the Lancashire coals produce tar containing benzol and phenol; tar produced from Cannel coal contains hydrocarbons of the paraffin series, which are extremely difficult if not impossible to separate by fractional distillation.

Professor Vivian B. Lewes shows, in the following table, the effect of temperature of carbonisation on the percentage proportions of the chief constituents of the gas produced :—*

Temperature.	400° C.	500° C.	600° C.	700° C.	800° C.	900° C.
Hydrogen, . . .	21·2	28·3	33·8	41·6	48·2	54·5
Saturated Hydrocarbons, .	60·1	56·2	50·7	45·0	39·1	34·2
Unsaturated Hydrocarbons,	6·3	5·8	5·0	4·4	3·8	3·5

The temperature of the coal or coke in the retort or oven, and the distance through which the gas with the tar has to pass to its exit, determine to a large extent the decomposition that takes place, and the production of a series of secondary reactions which alter the final product of both gas and tar. The shape and size of the oven or retort thus provides a means of producing complete changes in the tar, both as regards its quality and quantity. Coal distilled at a low temperature, with free exit for gas and tar, will result in the production of a tar exceedingly rich in the paraffin series of hydrocarbons, but deficient in pitch; coal distilled at a high temperature in a vertical, wide oven will produce tar very similar in percentage of pitch, but of quite a different composition as regards the other hydrocarbons. This is due to the filtering process which

* *Journal of Royal Soc. Arts*, 1908, p. 851.

occurs during the passage of the gas and tar to their exit through the column of comparatively cold coal.

Another effect of passing the gas through incandescent coke, even at a moderate temperature, is to alter the constituents of both the gas and the tar it carries with it, so that when it is claimed that gas and tar have been produced at a low temperature—that is, have been formed from the coal at only 450° C. —it must be remembered that they leave the interior of the coal at this temperature, and they will probably pass through a temperature of 100° C. higher, before they gain their exit from the retort; and this fact must be taken into consideration when forming an opinion as to the constituents of tar produced at a certain temperature; a fixed temperature throughout a retort or oven, when charged with coal, is impossible during carbonisation; the larger the retort or oven, the greater will be the difference in temperature between its separate zones of heat, from the centre to the circumference. One of the most difficult matters for propounding a theory as to its formation is that of the production of tar in coal distillation; so many factors are at work in diverging directions, and the tar is of such a complex nature, chemically, that any theoretical formula would be impossible. Certain facts are known, that is, certain results follow certain operations, but are extremely difficult to co-ordinate with precision, owing to the delicacy of the operation by which any slight variation produces a reaction different to that anticipated. The difficulty of maintaining constant temperature, already referred to, is one of the chief causes. Co-ordination in trials in the laboratory may be approximately true, but when trials are carried out in bulk, in large retorts or ovens, difficulties as to precision then occur in connection with the countless number of circumstances that govern the temperature of carbonisation, operating upon a mass of coal during a certain period of time. That is to say, it would be extremely difficult to guarantee the same output of coke, gas, tar, ammonia, or benzol from a given quantity of the same coal of the same quality and analysis day by day, even in the same retort or oven. It is, therefore, well to remember that figures tabulated to represent the character or constituents of gas or tar from a certain coal are approximate only; they cannot be definitely fixed, because of the difficulty above referred to on the one hand, and the divergence in constitution of the same coal in different pieces on the other.

The value of tar at the present day depends upon its constituents, and these constituents, as already pointed out, depend upon the temperature of carbonisation producing the tar; if it is proposed to distil the tar for the purpose of obtaining benzol spirit, and the constituents for the production of coal-tar colours, it is found that tar produced at a high temperature will prove the one containing the "*benzenoid*" series of hydrocarbons, that constitute the raw material for this purpose (such as benzene, naphthalene, toluene, xylene, anthracene, etc.). Those tars distilled at a low temperature will prove to be useless for the purpose, and will belong to the fatty series of "*paraffinoid*" tars, and will produce lubricating and burning oils and solid paraffin. In connection with the yield of benzenoid or paraffin tars, although the temperature of carbonisation of the coal has a great deal to do in determining the issue, it does not account for the total influence in either direction; the other factors that often characterise the tar are the chemical composition and physical condition of the coal operated upon. The coal from the older coal measures is generally richer in the benzenoid hydrocarbons, while that of more recent formation is richer in the phenols and paraffins. This is not all, however; low or high-temperature carbonisations give different results; also the method of carbonisation or

application of the heat, as observed above, also plays an important part in determining the result. That is, where coal is carbonised in a thick mass at a high temperature, a tar of a mixed character will result, whereas the same coal, carbonised at a high temperature in thin layers, will result in the production of tars rich in benzenoid hydrocarbons, the reason being that the heat in the first case has to pass from the walls of the oven or retort at a high temperature, coking the coal adjacent to the sides at a high temperature, and producing gas charged with benzenoid tar, but as it penetrates into the thick mass of cold coal, the temperature of distillation will be very considerably reduced, and tar of the paraffinoid series will be produced. The narrow, horizontal coke oven, and the high-temperature gas retort, have in their practical working the conditions for the production of the benzenoid tars, while the tars produced in the Beehive oven, as also in the Jamieson oven, are characterised as the paraffinoid series.

Free Carbon in Tar.—Free carbon is found in all descriptions of coal tar in one form or another, according to the way in which it enters the tar; coal or coke in fine division will, no doubt, be carried over from the retorts into the hydraulic main, clinging to the particles of tar suspended in the gas, and Köhler proved that carbon may be carried over with the gas, after decomposition of the latter by contact with the hot sides of the retort; tar containing a large quantity of free carbon is difficult to treat by distillation down to hard pitch, on account of the injury that may accrue to the stills.

Coal Tar, its Storage, Condensation and Distillation.—Long before the advent of gas lighting and the carbonisation of coal for this purpose, the process of distilling tar was known. In the Patent Office records there is a patent granted to Henry Haskins, Aug. 7th, 1746, for a "New method of extracting a spirit or oil out of tar, and by the same process produce the finest pitch." It is very probable that the tar proposed to be so treated was wood-tar. Haskins states that the process consists in treating the tar in a double-necked, pelican-headed still, made of glass, iron or copper, and with a capacious receiver; he proposes to heat this still for six hours, at first with a fire of the "first degree," in order to "comminute" the particles thoroughly; he then raises the heat to the "second degree" for another six hours, and lastly for another period of three hours he uses a fire of the "third degree"; by this time, he says, a "pale acid phlegm" will come over into the receiver, which must be changed when the "fetid volatile oil" appears, or the spirit rises; then a black, glutinous oil will come over into the receiver. He then proposes to rectify the "volatile or light oil" by repeated distillation "for many uses in physic." Lastly, the pitch is found in the still at the end of the operation.

In 1815 Accum proposes to distil coal tar by boiling it down in closed vessels for the purpose of obtaining a volatile oil, as a cheap substitute for spirits of turpentine.

It is supposed the first tar distillery was erected in 1822, near Leith, by Dr. Longstaffe and Dr. Dalston, who sent the volatile oil or spirit to Mr. Mackintosh for dissolving rubber for the manufacture of waterproofs.

Storage of Tar.—To within a few years, when the production of tar was made by the carbonisation of coal, for the production of lighting gas, its collection and storage became a matter of serious difficulty, and therefore, means were adopted for getting rid of it, such as burning it under the retorts; but with the advent of the by-product coke ovens, and the dyestuffs industry, and the demand for pitch, large establishments have been erected with immense plants to carry on the industry of separating the valuable constituents of coal tar from the pitch.

The difficulty of collecting the tar from small, isolated gas works is still a matter involving long and expensive carriage, and it does not pay to move it; but where the gas works is situated on a canal, and within reasonable distance of the tar works, it is quite easily disposed of, as water carriage is generally considered the cheapest and best for this purpose. Boats have been constructed to hold 10,000 gallons. Railway waggons have also been constructed with tanks for transporting tar. This mode of transit has been more used on the Continent than in Great Britain. In Germany these tank waggons are frequently provided with heating apparatus, consisting of steam tubes, connected with the steam-heating system of the railway carriages, in order to keep the tar from freezing in the winter. From the canal boats, or the railway trucks, the tar is generally transferred to storage tanks erected high enough to enable the tar, after the water has been separated, to run by gravitation down into the tar stills. Other storage tanks are constructed in the ground, from which the tar is either pumped into the elevated tanks or direct into the stills. These below-ground storage tanks are generally of very large dimensions, in order to accomodate tar coming to hand under contract to the distiller from the gas works, when any stoppage of the process of distillation may occur; by this means also an equilibrium may be obtained between the winter periods, when the gas works are making a large quantity, and summer periods, when a small quantity is produced, and the result is that the tar stills may be regularly employed throughout the year. These underground storage tanks are seldom made of iron, on account of corrosion and cost; they are generally constructed of brickwork, laid in cement, of circular shape, and puddled with clay on the sides and bottom.

Tanks are perhaps more satisfactorily constructed of ferro-concrete, as in this case the danger from cracks developing in brickwork is to a large extent avoided; when a crack does occur in a brick tank, it is practically impossible to have it satisfactorily repaired. Tanks made of ferro-concrete can be constructed either above or below ground.

Condensation of Coal Tar.—When coal is carbonised either in retorts or ovens and the gas is procured, the latter carries with it the tar in finely-divided particles or globules, some of which condense on the sides of the ascension pipes, and fall back again into the oven or retort, whilst the greater proportion is carried forward with the heated gas, a small portion being deposited in the hydraulic main; another portion of the tar, the most difficult to condense, passes through the hydraulic main into the coolers, where the aqueous vapours are to a certain extent condensed; but as the tar is generally present in the gas in a very finely divided condition, in fact, in the form of a mist or fog, it is still carried forward through the exhauster into the tar extractor, which is a mechanical apparatus for forcing the particles of tar together; simply cooling the gas does not condense these particles, and several methods have been proposed to effect the condensation, some of which have proved more or less successful in practical operation. The oldest form, and one that has perhaps had universal application for this purpose, in gas and coke works, is that of Pelouze and Audouin, who are, however, according to Colladon,* not the real inventors of the process, although it is generally known by their names; it consists of an apparatus through which the gas is passed after leaving the coolers, as shown in fig. 184.

The apparatus consists of a cylindrical vessel, with an inlet gas pipe situated near the base, as in figs. 185 and 185*a*, and an outlet gas pipe near the top, on the opposite side; within this cylindrical vessel are three chambers, the lower chamber forming the inlet, the middle the drum seal, and the upper the outlet

* *Compt. Rend.*, lxxvii., p. 819.

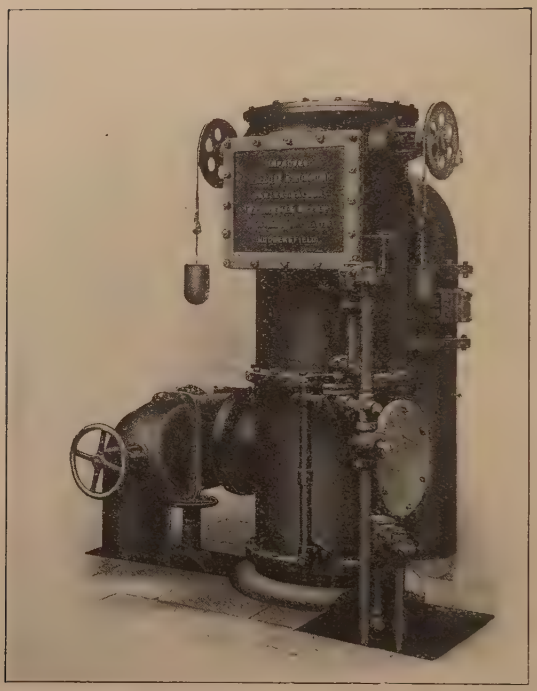


Fig. 184.—Pelouze and Audouin Tar Extractor (" Holmes " Patent).

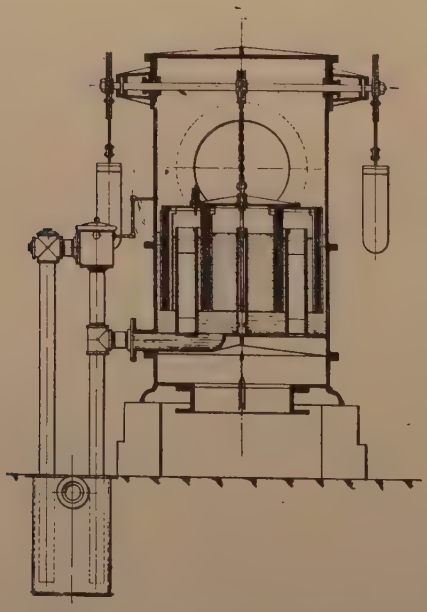


Fig. 185.—Sectional Elevation of the " Columnless " P. & A. Tar Extractor.

chamber. There is a horizontal shaft with external ball bearings, and connected to a balance weight, which enables the drum to rise and fall according to the quantity of gas passing through, without any variation in pressure. The movable drum is formed with one or more rows of perforated or slotted plates, which are so spaced as to give a large surface against which the gas impinges as it strikes the plates in order to pass through the holes. The improvement in this apparatus, patented by Messrs. Holmes, of Huddersfield, is in the remov-

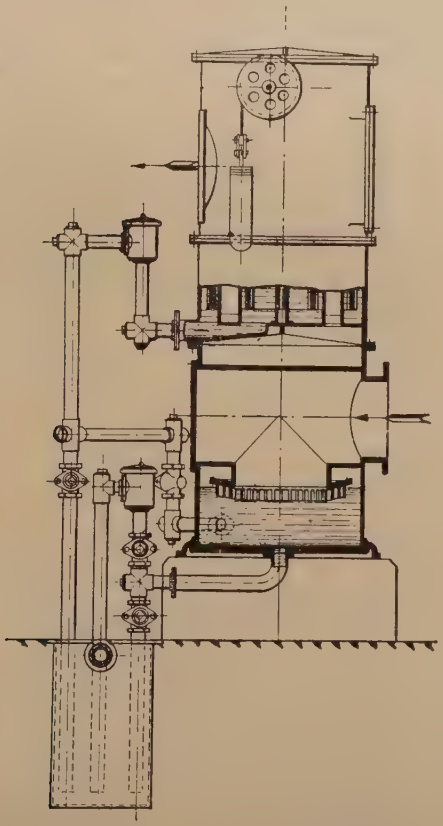


Fig. 185*a*.—Sectional Elevation " Contractor " Type of the Holmes' " Columnless " P. & A. Tar Extractor.

able perforated plates, figs. 186 and 187 ; each bundle of plates forming the drum can be easily detached and removed, through the manhole, for cleaning purposes. The drum is also fitted with an automatic bye-pass, in which the counterbalanced drum is provided with relief valves, normally held closed by springs, but which, on the drum descending too low, are automatically opened, the resistance of the springs being overcome by the unbalanced weight in the event of the supporting rope accidentally breaking. The gas laden with the fine globules of tar in passing through this machine loses the major part ; very little is carried further forward unless the gas is forced through too quickly ; the only drawback to a machine of this description is that the tar may

consolidate on the plates and stop up the perforations ; to remedy this, Messrs. Holmes make the plates removable. The total removal of the tar from the gas is an absolute necessity if a first-class sulphate of ammonia is desired, because traces of tar discolour the sulphate and reduce its market value. A large

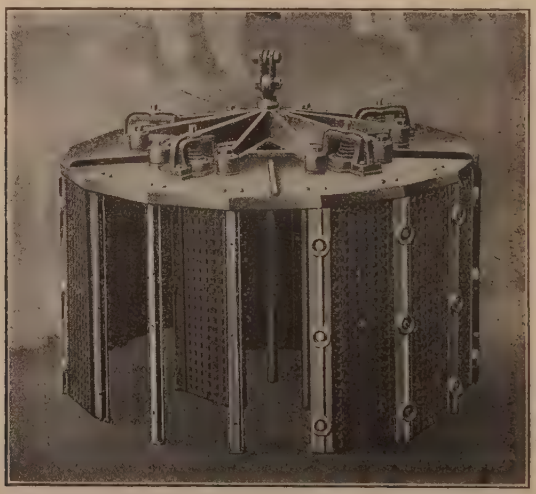


Fig. 186.—"Holmes" Patent P. & A. Drum with sections of plates removed.

number of experiments have, therefore, been undertaken in different forms of apparatus for achieving this object. The Otto Coke Oven Company intro-

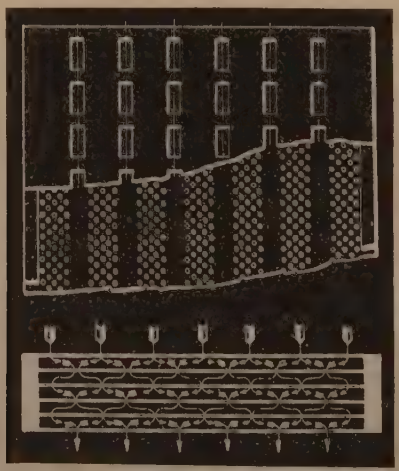


Fig. 187.—Part Sectional Elevation, and Plan View of one Section of Drum, showing Perforations and the Passage of the Gas through the Plates.

duced a process of cleaning the gas from tar, which has been more or less successfully operated at a great many of their by-product installations (B.P. 12,809,

A.D. 1908). A section of the apparatus is shown in fig. 188 ; *a* is an injector, to which tar is fed by the pipe, *b*, from the pump *c* ; the crude foul gas from the coke ovens is brought to this apparatus by means of the pipe *g*, which enters the outside case of the injector ; a spraying device, *s*, enters this gas main, and is connected to a branch pipe, *f*, leading to the tar pipe *b*. By this means tar is sprayed on to the surface of the injector, and any accumulation of thick tar is thereby washed down ; the tar injected through *a*, together with the tar condensed by this action from the foul gas, passes down the pipe, *h*, into the catch box *k*, and as much of this tar as is necessary flows back by the pipe, *m*, to the pump *c* ; the pipe, *n*, is for the purpose of running off the excess of tar from the box *k*. The cleansed gas passes away by the pipe *d*. The Otto Company claim that "the economical advantage of using this tar injector resides in the fact that, the tar being removed from the gas thereby, without removal of the ammonia, the gases can be passed directly to the ammonia

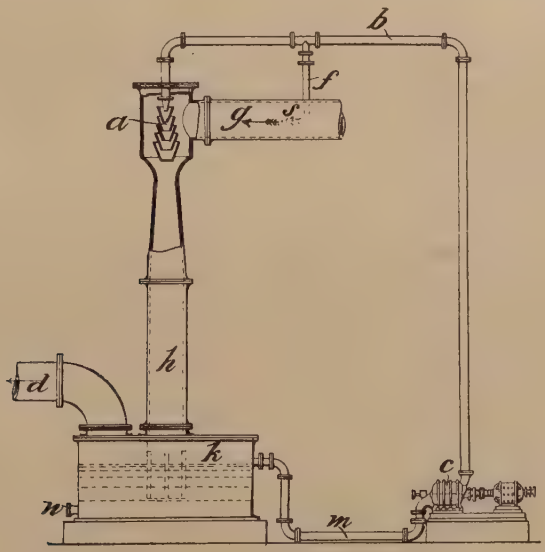


Fig. 188.—Section of Apparatus for Tar Extraction. "Otto" Process.

absorption apparatus, an object which hitherto has been difficult of attainment, because of the tar contained in the gas." The injector being supplied with tar under pressure from the pump *c*, this tar is divided up by the injector into a spray, which passes into the surrounding volume of gas, but in a very much coarser state than the tar in the surrounding gas. These coarser particles, striking against the finer particles of tar in the gas, cause them to form larger globules, and by this means the gas is cleansed from the tar. Certain precautions are necessary when using this apparatus, especially in very cold weather, owing to the tar in the pump pipes becoming too cold, the tar consolidating and making a spray very difficult to form satisfactorily ; a certain temperature, therefore, must be maintained, on account also of the non-condensation of ammonia from the gas at this stage of the operation. It was maintained that the higher the temperature at which this operation could be carried on, the better the result ; but in 1909 Dr. Otto made the following improvement,

B.P. 26,124, in which he states :—" It has been pointed out that the temperature of gases from which tar is to be separated by a tar spray should exceed 40° C., and it has been stated that the higher the temperature above this limit the better, when the recovery of ammonia is in question, the best temperature being between 100° and 200° C. Now, according to the present invention for the successful working of the scrubbing agent, the latter should have a temperature not exceeding 80° C. and not substantially below 80° C. It follows that the temperature should be maintained as near 80° C. as possible. If this temperature be adopted, the gas remains sufficiently hot for the direct precipitation of all the ammonia it contains. There are various modes of ensuring that the temperature shall not exceed the limit named. Thus, care may be taken that the temperature of the gases at the time they are scrubbed with the tar is such that the temperature of the latter cannot exceed 80° C., although

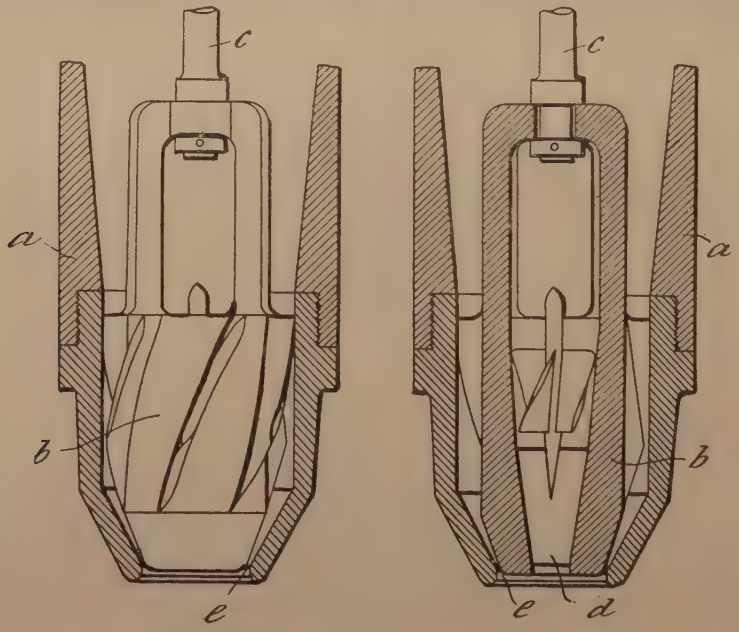


Fig. 189.—Sections of Nozzles for Tar Extraction. " Otto " Process.

in this case there is some danger that the content of steam in the gases may lead to incomplete precipitation of the ammonia as sulphate. Another mode is to supply the scrubbing agent in such proportion that the temperature cannot exceed that limit."

That certain adjustments as to the volume of tar and gas were necessary in this method of condensing the tar is obvious from the further invention of Dr. Otto, B.P. 17,548, of 1910, in which he adapts another form of nozzle to his injector, and states, " In the practice of separating tar from gases by means of a spray of tar, or of tar and ammoniacal liquor, injected into the flowing gas, it is desirable to adapt the quantity of liquid to the volume of gas which happens to be passing at any given time. A mere adjustment of the quantity by throttling the supply pipe feeding the injector is inadmissible, because the speed of flow through the injector, being thereby varied, the form

of conical spray produced would be altered and become less efficient." To obviate this, Otto provides a nozzle in which the orifice through which the tar passes to produce the desired spray admits of no more liquid than " that necessary for separating the tar from the gas when the volume of gas passing at any time has been reduced to a minimum, while for increasing this quantity of liquid there is a separate adjustable annular orifice concentric with the orifice aforesaid." Figs. 189, 190, and 191 show this nozzle. Fig. 189 is partly an elevation of the inner and partly a vertical section of the outer case ; figs. 190 and 191 are horizontal sectional plans. The casing, *a*, is connected to the tar supply pipe, which may contain tar and ammoniacal liquor under pressure from the pump, *c*, in fig. 188 ; within this casing is the nozzle *b*, with orifice *d*, of a certain fixed dimension. The nozzle is formed with helical grooves on its external surface ; the casing forms a kind of spiral passage for the liquid to flow through ; the grooves are contracted at their extremity at *e*, when the nozzle is in its seat in the casing ; by this means the tar and ammoniacal liquor form a twisting spray when injected through the contracted orifices of this nozzle into the surrounding gas in the pipe *h*, fig. 188.

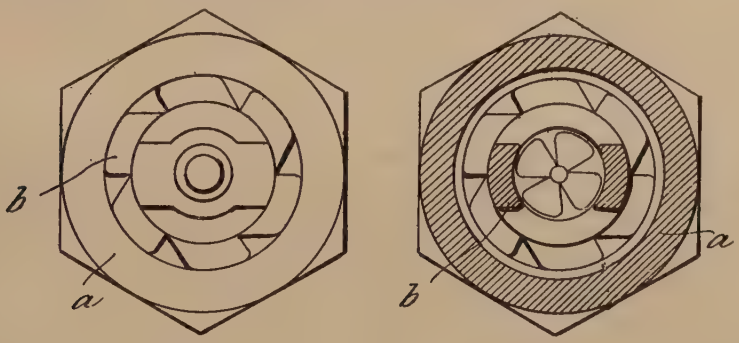


Fig. 190. Fig. 191.

Plans of Nozzles for Tar Extraction. " Otto " Process.

Another method of tar separation by the Simon-Carves By-product Coke Oven Company in conjunction with Edward Lloyd, B.P. 8379, A.D. 1910, is applied to coke oven gases. The process consists in causing the hot gases from the coke ovens to pass through a " static centrifugal separator " with such a velocity that the centrifugal action will separate the heavier portions of the tarry matter from the gas. The gases are then passed through a " dynamic separator," also with centrifugal action, in which the lighter and more finely-divided particles of tar are separated. The gases then pass on to the ammonia apparatus. Fig. 192 shows the arrangement of this apparatus. The hot gases are led to the centrifugal separating apparatus, A, fig. 192, through the pipe B, which is of the " cyclone " type with a central discharge, C, in the bottom for the tarry matter and ammonia liquor, and a gas discharge pipe, D, at the top, through which the partially-freed gas passes to the " dynamic separator," E ; the latter has a rotary action, by which the tarry particles are caused to unite and condense, whence they are discharged by means of the pipe F. This centrifugal dynamic separator is known as the " Crossley " separator ; but a centrifugal apparatus of this type is incapable of imparting to the gases pressure sufficient to cause them to flow forward, and it is, therefore, necessary

for this purpose to have recourse to a separate "exhausting or blowing apparatus," H, from which the gases are passed by the pipe, J, to the ammonia apparatus. Another form of this process is illustrated in fig. 193, where it is claimed that the above-mentioned "exhausting or blowing" apparatus is superseded by the "dynamic centrifugal separator," E; such a separator,

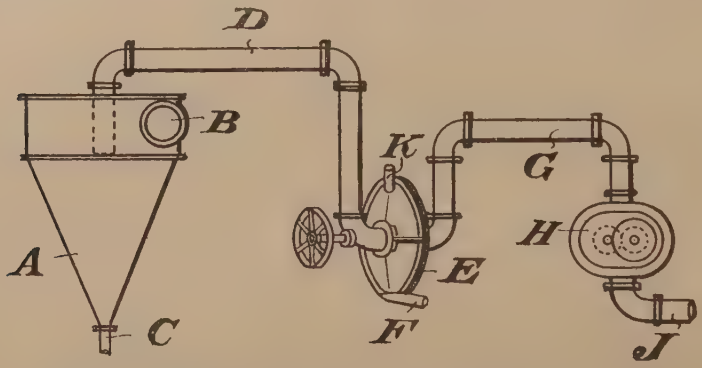


Fig. 192.—Diagram of Tar Separator. "Simon-Carves" Process.

it is stated, is an ordinary "centrifugal fan or pump," to the eye of which the gases from the static separator are delivered through the pipe D, and from the outside casing of which the tar particles are condensed, and the freed gases led away through the pipe G, while the condensed tar is allowed to flow out through the trapped pipe F. It is also proposed to inject tar into the pipe in

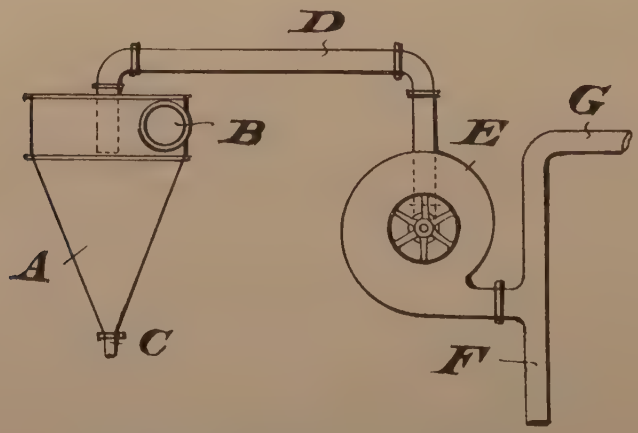


Fig. 193.—"Simon-Carves" Tar Separator.

the form of a spray at a temperature above the dew point of the gases, as the gases enter the static separator.

The (Semet-Solvay) Coke Oven Construction Company, Ltd., have a system of tar separation as shown in fig. 194, where the hot gases are maintained above

the dew point of water vapour, and the tar is recovered by washing with tar in the apparatus, by means of bubbling the gas through a bath of tar. By controlling the temperature of the gases, and of the tar, and by variations in the volume of tar used in washing, very effective de-tarring is accomplished; the method as shown in fig. 194 is to exhaust the gas through the tar extractor, and then push it forward through the subsequent processes for ammonia, benzol, etc. This process is called the direct process, B.P. 7915, A.D. 1910, and is in operation at Seraing, in Belgium, but "it has not proved that there is any gain in simplicity and certainty of operation, or in prime cost of apparatus, or in water consumption. The naphthalene remains in the gas and is separately recovered by sudden cooling and washing with anthracene oil. Any ammonia fixed as chloride remains in the tar, and is dissolved by washing the tar with liquor, and the solution concentrated as a separate product. The "dry" main and hot tar circulation essential to the process yield a tar low in naphthalene, light oils, and creosote oils, with a high proportion of pitch, which the tar distiller shows a disinclination to handle. On the whole, when any choice is left to the company they advocate the semi-direct process, especially in districts where the yield of fixed ammonia is high. The semi-direct process (Marr's patent, No. 6291, A.D. 1913) is shown in fig. 195. In this process about 25 per cent. of the ammonia is retained in the gases, and this together with all the fixed ammonia is distilled off with steam and lime, and the vapours of distillation are added to the coke oven gases and pass in a common stream through the sulphuric acid. To appreciate the essential features of this process, it is necessary to remember that the cooled gases from the coke ovens are already in the saturated condition, and any added water-vapour must, therefore, be deposited in the saturater and cause an excessive "make" of liquor. Koppers endeavours to mitigate this deposition in the bath by superheating the gases to increase their capacity for water vapour. The Mont Cenis method is to dry the ammonia steam previous to its admission by condensing the bulk of the steam in a cooler. In Marr's process the ammonia steam is added to the coke oven gases without cooling the former or superheating the latter. When the equilibrium temperature (something higher than the initial temperature of the gases) is established, the surplus water vapour or supersaturation is removed by passing the mixed gases through a separator suitable for dealing with water fog. As a result, less water is carried into the acid bath, and the temperature on leaving the bath is higher, the gases having correspondingly higher capacity for water vapour, and the concentration of the mother liquor is maintained,

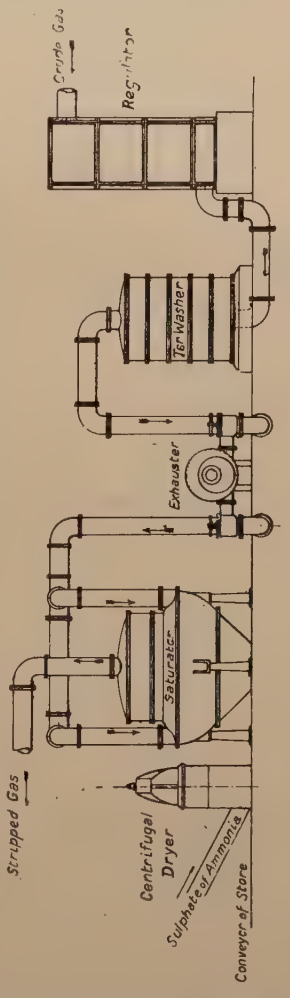


Fig. 194.—"Semet-Solway" Tar Separator.

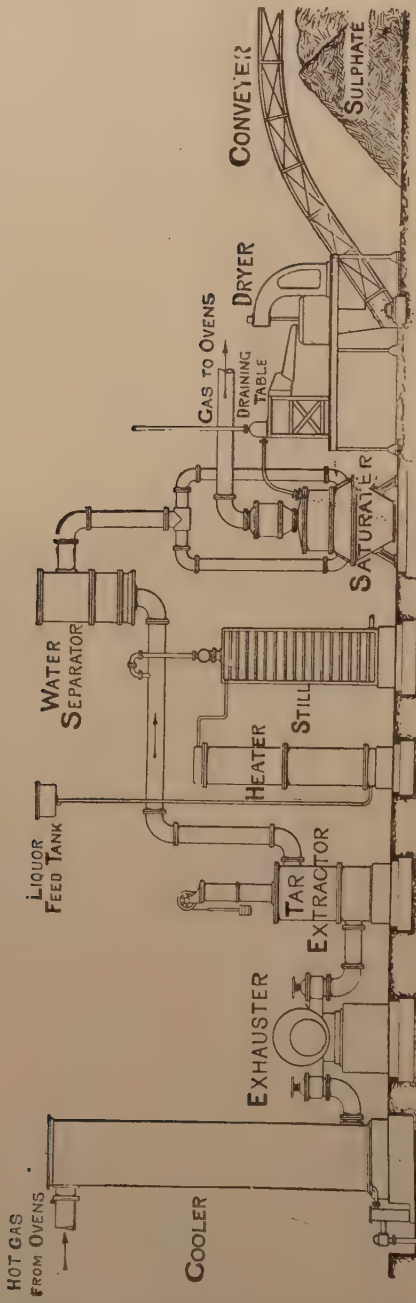


Fig. 195.—Direct Ammonia Recovery Plant.

even if considerable water additions are made in washing the salt, the draining table, and centrifugal basket." *

* Private communication.

A tar-separating apparatus, B.P. 821, A.D. 1912, and B.P. 569, A.D. 1913, was designed by the author for the purpose of saving expense in large plants, and for efficiently cleansing the gas from tar, ammonia, and benzol. Figs. 196, 197, and 198 show this apparatus in section and plan, and are more applicable

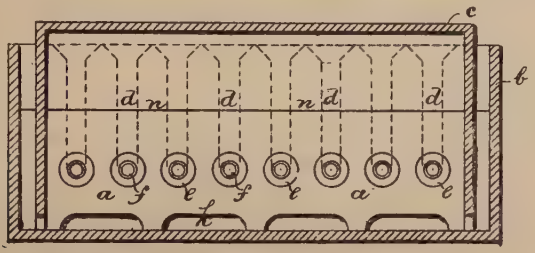


Fig. 196.—Section of " Armstrong " Tar Extraction Apparatus.

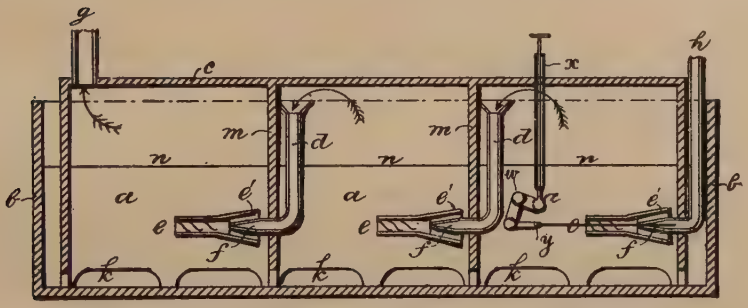


Fig. 197.—Section of " Armstrong " Tar Extraction Apparatus.

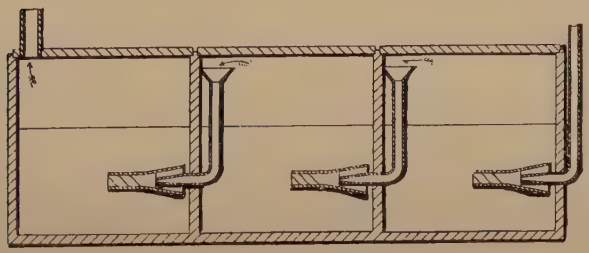


Fig. 198.—" Armstrong " Tar Extraction Apparatus (Section).

to the recovery of tar, although apparatus shown in figs. 199 and 200 can be used for the purpose; they are more particularly adapted to the recovery of ammonia as sulphate, and of benzol. The gas is drawn off hot from the condensers, where the surplus water and tar are obtained, and by an exhauster-compressor the gas is made to flow through pipes constructed inside the tanks, *b*, *b*, figs. 196 and 197. The ends of these service pipes are furnished with jets *f*; these are so constructed that each discharges the gas through the orifice of a larger rifled tube *e'*, which may be made of a conical shape. When, therefore, the gases pass through it, there is a partial vacuum formed, and as the jet is immersed in liquid tar, the liquid is drawn into the tube, and passing through the rifled portions it acquires

a twisting motion, by which the liquid is brought into very intimate contact with the gas, both of which, by this action, are finely divided. The difficulty of blowing gases through liquids ordinarily has been that large bubbles are formed that escape to the surface, only a portion of their cubical contents having come into direct contact with the liquid. By this method intimate contact between the gas and liquid is made by the compressing, twisting, and spraying nature of the action that takes place in the tube, beneath the liquid tar. The gas, passing up to the surface in finely divided particles, is thereby thoroughly scrubbed and washed clean from tar. This process is repeated, as in fig. 197, through two or more chambers in the tank. The tank has overflow pipes to carry off the surplus tar, and the cleansed gas makes its exit by means of the pipe *g*; for the purpose of keeping the jets free from condensed tar or other matter, a cleaning wire is inserted with an apparatus, *x*, for working it upon a crank, *w*, backwards and forwards. The direction taken by the gas through the apparatus is shown by the arrows. The tanks can be water or steam-jacketted in order to keep the liquid tar at the requisite temperature,

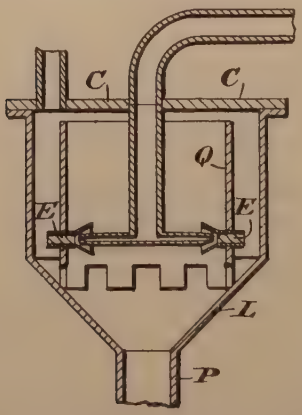


Fig. 199.—"Armstrong" Tar Extraction Apparatus.

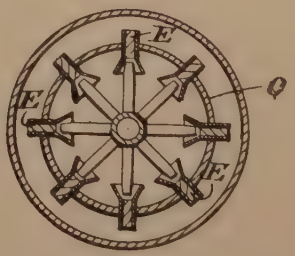


Fig. 200.—"Armstrong" Tar Extraction Apparatus.

so that the gas may not be cooled down to the dew point, and thus the ammonia is kept from condensing.

Gas Exhausters.—In all modern plant for the carbonisation of coal either in the gas works, making illuminating gas, or at the coke ovens, where the by-products are saved, the gas is generally exhausted or drawn off from the retorts or ovens by exhausters, driven mechanically; other methods have been tried, such as that devised by Messrs. Korting, using a steam injector, but the process generally applied for this purpose is the former method using mechanically driven exhausters or blowers. Exhausting the gas relieves the pressure inside the retorts or ovens, and proves a great help in the satisfactory working of the process of carbonisation, and at the same time imparts the necessary pressure on the crude gas to push it through all the subsequent processes for the recovery of the by-products, tar, ammonia, and benzol; a description of this apparatus is given on p. 398, Chapter XII.

Distillation of Tar.—The by-products from the carbonisation of coal are usually summed up in the *tar*, *ammonia*, and *benzol* obtained directly from the

gas in a continuous process; but, with regard to the first of this list, namely the tar, this is again submitted to a process of fractional distillation for the purpose of obtaining an additional amount of benzol spirit, and pitch, with numerous other matters contained in this most complete substance. The process of fractional distillation of coal tar is conducted in stills, constructed of iron, and heated by means of a fire; but other means have been designed using steam or electricity, as will be noticed subsequently. With regard to the ordinary method in the tar stills, using a direct fire, the object is to get rid of the non-volatile (or practically so) constituents in the shape of pitch, and subsequently to submit each distillate independently obtained to further working up, where necessary. The first process that is necessary is the dehydration of the tar—that is, freeing it from the admixture of ammoniacal liquor, which otherwise renders the processes of distillation troublesome, by reason of the formation of steam, causing the tar to "bump" or actually to be jerked out of the still. In order to do this great care has to be exercised; slow firing is used, but if the tar has been stored for some time, the excess of ammoniacal liquor can be run off, and the tar freed from water to a large extent in this way; but storage for large quantities of tar sometimes is not available, and the tar comes to the still with ammoniacal liquor still in suspension, and the first warming up of the stills has thus to be carried on carefully. In order to avoid this first stage of dehydration, certain processes and apparatus have been designed; Messrs. J. and R. Dempster described an invention for the purpose, B.P. 3245, A.D. 1882. Their object is accomplished simply by gravitation, allowing the water to flow over into a cup situated at the top of a pipe fixed in the tank containing the tar, the cup being raised or lowered by means of an adjusting screw to suit the level of the tar and liquor in the tank. Other separators are in use for this purpose, most of which are designed upon the same principle, that of floating off the water into suitable receptacles by gravitation. There are processes consisting of a preliminary heating in large boilers, whereby the tar becomes thinner, and the water rising to the surface being from time to time drawn off by a stopcock fixed at the upper level to which the boiler is filled, but in this method additional apparatus is required to condense the volatile portion produced by the heating; such a process was patented some time ago by Th. Foucault, in which he constructs a sort of rectangular boiler, divided into two unequal parts by a perpendicular partition, and another partition dividing the boiler longitudinally and fixed in a sloping position; the boiler is heated only at one end, that forming the shortest portion of the boiler divided by the vertical partition; the tar as it is heated rises in this portion, boils over, and spreads out on the longitudinal plate, where it runs down and is cooled back into the lower part of the boiler; an upper chamber receives the vapour, which condenses therein, and is carried away by a syphon tube. Fig. 201 is a vertical section, and shows the arrangement of this apparatus; F is the fireplace, B is the boiler, C the vertical partition, D the longitudinal partition; A is the tar boiling over on to the longitudinal partition down which it runs into the lower portion of the boiler, then through the aperture, G, into the compartment that is heated by the fire; H is the flue to the chimney; T is the tank over the boiler filled with cold water, under which is a condenser, where the vapours from the boiler condense and run out through the syphon S. The tar is introduced through the tube K; the height of the tar in the boiler is regulated by means of the cock E. The tar after dehydration is run off by the tube L.

Considerable difference of opinion existed regarding what form the tar still

should take; some early forms were merely longitudinal boilers; often old steam boilers were made use of for the purpose, with a fire placed underneath them,

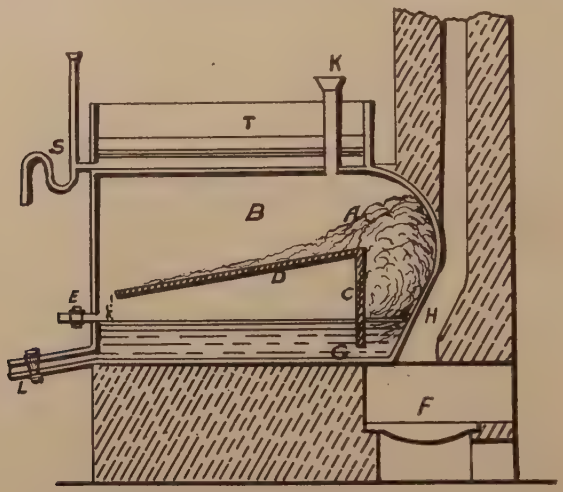


Fig. 201.—Section of Tar Still, with Internal Partitions.

but these could not be satisfactorily worked, requiring a large consumption of fuel in comparison with the quantity of tar worked up; further disadvantages

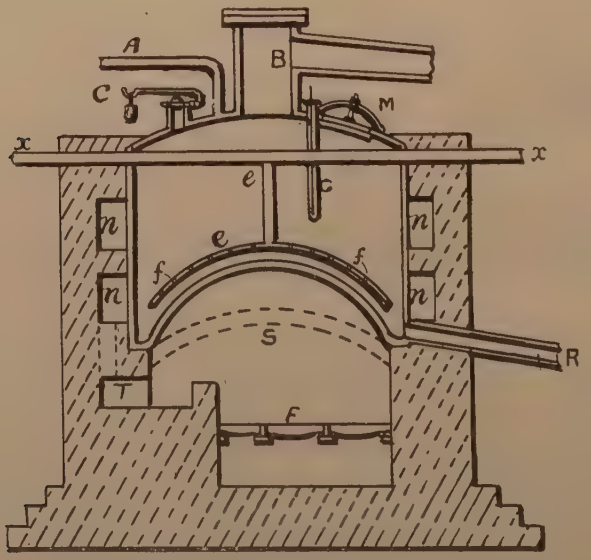


Fig. 202.—Section of Tar Still, with Concave Bottom.

were the danger of frothing, and the length of time required in working, together with frequent repairs. No doubt these ineconomical considerations opened

the way to a more profitable method being adopted, using the upright still with the concave bottom. Fig. 202 is a section showing the way this still is constructed. Formerly the stills were made of cast iron, but when stills of large dimensions were desirable, castings were limited in size, and although they were easily managed—that is, the cast iron was less liable to be burned away by the fire than wrought iron—the danger from cracking, the longer time required by the heat in penetrating through the larger thickness of iron, and the necessarily small dimensions of the still, resulted in cast iron being abandoned in favour of a more suitable material; stills made of boiler plate, riveted together, have proved to be more economical in every way; they are easier to clean from the pitch coke without endangering the metal; they do not crack, and require less attention than those of cast iron. They can be made of large size, but there is a limit to size, for other reasons; a still that cannot be worked off in from 15 to 16 hours is too large, as night work is not desirable; charges of from 15 to 20 tons are about the average, and are preferred, because they can be worked off in from 10 to 12 hours, obviating night work. Some stills in Germany have been constructed as large as to hold 50 tons, but it is very doubtful if these very large stills are so economical or satisfactory as those of smaller dimensions.

The still illustrated in fig. 202 is of the upright type, and constructed of boiler plate; the bottom is constructed domed-shape, of the same curve or radius as the radius of the still body. Some stills have a manhole formed in the top cover, shown at M, fig. 202; if the upper off-take be made large enough, as at B, the manhole is superseded. The running-off cock is shown at R, a thermometer is inserted at G, and in some stills a mechanical stirrer, formed of steam tubes *e*, with nozzles *f*, is constructed inside the still. The steam is introduced by the pipe *x*, which has branches, *e*, arranged over the bottom of the still; the steam that is used is generally superheated dry steam for finishing the process by preventing overheating and facilitating the exit of the heavy hydrocarbons. H. W. Fenner introduced mechanical stirrers, together with steam (B.P. 13,629, A.D. 1884) by forming the central shaft hollow, with branch pipes for the steam, the whole arrangement being made to rotate by means of gearing at the top of the still.

Not the least important part of a tar still is the setting; most of the trouble experienced in the past has been to a large extent due to the way in which heat has been applied to the still for the distillation of tar. The still shown in fig. 202 has its bottom as well as its top made in the form of a dome; this shape ensures more security to the plates with regard to expansion and contraction, and at the same time brings up the heat from the fire grate, F, right into the centre of the mass of tar, thus giving an increased amount of heating surface over that of a flat-bottomed still. All stills should be protected from the direct action of the flame; this has been accomplished in two ways, either by drawing off the flame into a flue, T, at one side, or by the insertion of a curtain arch of refractory material to cover all or part of the bottom of the still, as shown in the illustration, fig. 202, at S, which represents the curtain arch; T is the alternative flue, which is carried round the still by flues *n*, *n*, when no curtain arch is used. The plates forming the still are lapped at the joints and riveted; the rivet heads are countersunk inside, in order to give a smoother surface; the plates are usually about $\frac{1}{2}$ inch in thickness, or a little more, at the top, where, strange to say, the plates are more exposed to corrosion than at the bottom, by reason of the fumes, or from the condensation of ammoniacal liquor, which rapidly corrodes the iron round the top of the still, but where the

tar covers the iron the latter is kept from corrosion. The tar still is fed with raw tar by the pipe A, and a safety valve is generally placed on the dome of the still, as at *c*, fig. 202. After the tar has been finished, the pitch is run off through the tube R; but in some kinds of stills this is superseded by a syphon, the pitch having been previously thinned down by an addition of tar oils, which are then drawn off.

A new kind of tar still was invented by Messrs. Hughes, Ruthenburg, and Dava, called the U or continuous still, for which is claimed the following advantages :—"Low initial cost, complete utilisation of heat, low fuel consumption, exact control of heat, fractions accurately separated, no coke deposit, no degradation of products, no resistance to flow, no stoppages, no repairs (?), automatic feed and discharge." Should all these advantages be realised, it will prove a boon to the industry. The still is divided into two types, the "Simple," and the "Compound." The simple type consists of a wrought-iron U-shaped vessel, to one arm of which heat is applied. The second arm is of smaller diameter and serves the purpose of balancing the tar undergoing distillation. The arm that is heated is provided with a jacket for the purpose of retaining the heat and maintaining the circulation of the tar. Tar is first introduced into the jacket, where the heat from the hot arm, which it surrounds, promotes the distillation, so that the light part of the distillate is separated, and conducted away by the still-head into the condensing coil, with which the jacket is provided; the partially distilled tar is pumped from the jacket into the hot arm interior, which is heated by an electrical element fixed in the centre of the fluid. This heater in the simple form is made up of several sections through a multiple switch, coupled up in different combinations for the purpose of maintaining different temperatures as required. The cooling action of the jacket produces an effect by which the base of the U is generally filled with a dense volume of tar, which has been deprived of its hydrocarbons, and is comparatively cool; the circulation being more active and practically confined to the hot part of the arm, this arm is provided with a still head and condenser for the condensation and collection of the various fractions. The compound type consists of as many "hot arms" as there are fractions of distillate to collect; a description of this invention is given in the specification, B.P. 25,845, A.D. 1912, and is much as follows :—Fig. 203 illustrates diagrammatically one form of the distilling apparatus, and fig. 204 is another form. With reference to fig. 203, three stills are shown, each consisting of an outer cylindrical vessel, A, having a domed top A^1, and containing an inner cylindrical vessel B. In the centre of this vessel is a compartment, C, which contains the electric heater; the electric current is supplied through convenient conductors D, which are passed through the dome by means of insulated stuffing boxes. The tar is supplied from a tank, E, through a pipe, E^1, to the bottom of the first jacket A; it rises up the annular space between the jacket, A, and the inner vessel B, and then flows over the top of this vessel and fills it. The tar is here heated by the electric element in the chamber C, and some of the distillate passes off through the opening provided for it at A^2 to the condensers. The heated tar passes out from the bottom of the vessel, B, through the pipe, F, to the next outer vessel or jacket in the adjacent still. The course of the tar in this second still is the same as just described with reference to the first still, the tar leaving the second inner vessel by the pipe F^1, and proceeding to the third still, and so on, from the inner vessel of the third or subsequent stills as may be in use, and becoming pitch from which all the volatile constituents have been abstracted; it passes through a pipe, F^2, to a vessel or column, G,

provided with an outlet, G^1, at such a height as to control the level in the several stills and to allow for a continuous flow of tar through them. The temperature in each still is regulated by means of the electric heater, which can be so adjusted to secure fractional distillation at various stages.

The pitch leaving the last vessel is at a high temperature, and as a means of cooling it, and at the same time making use of the heat abstracted, the cold tar is run through the hot pitch in pipes, previous to its being fed into the first still.

Another method of arranging the stills employed by the inventors is shown

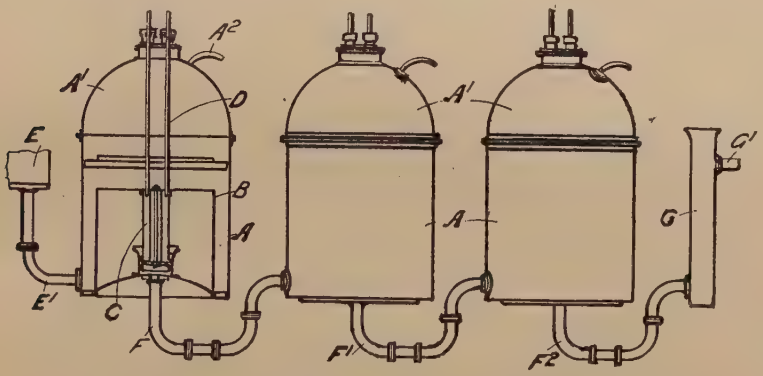


Fig. 203.—" Ruthenberg " Electric Tar Still.

in fig. 204, where four stills are shown ; each still is furnished with the internal details shown in fig. 203, but not shown in fig. 204. In this arrangement the tar is first passed into the first still by the pipe, H, to the inner vessel B^1, thence through the pipe, H^1, to the inner vessel, B^1, of the second still ; then through the pipe, H^2, to the inner vessel of B^1 in the next still, and so on to the last inner

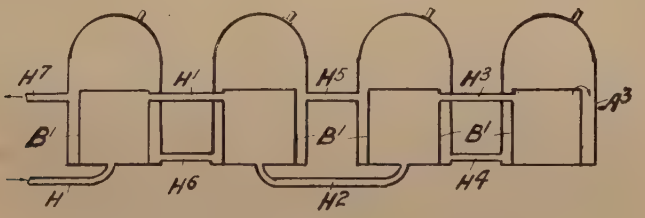


Fig. 204.—" Ruthenberg " Electric Tar Still.

vessel by the pipe H^3. From the last inner vessel, B^1, the material passes from the jacket, A^3, of the last still, and then proceeds through the series by the pipes, H^4, H^5, H^6, through the jackets of the stills to the first still jacket, and leaving by the pipe H^7, giving up its heat in its course, before it makes its exit to the pitch receptacle. This system may be worked by gravity, but when this cannot be done the tar is pumped through. The inventors state that the electric heating is convenient for fine adjustment of fractionating temperature, but the stills can also be worked by means of hot gases passed through them

in pipes; with electric heating no overheating is caused, the temperature is certain, and there is no deposit of carbon, as the latter is only deposited through overheating.

In small plants dealing with small amounts of tar it is not usual to carry

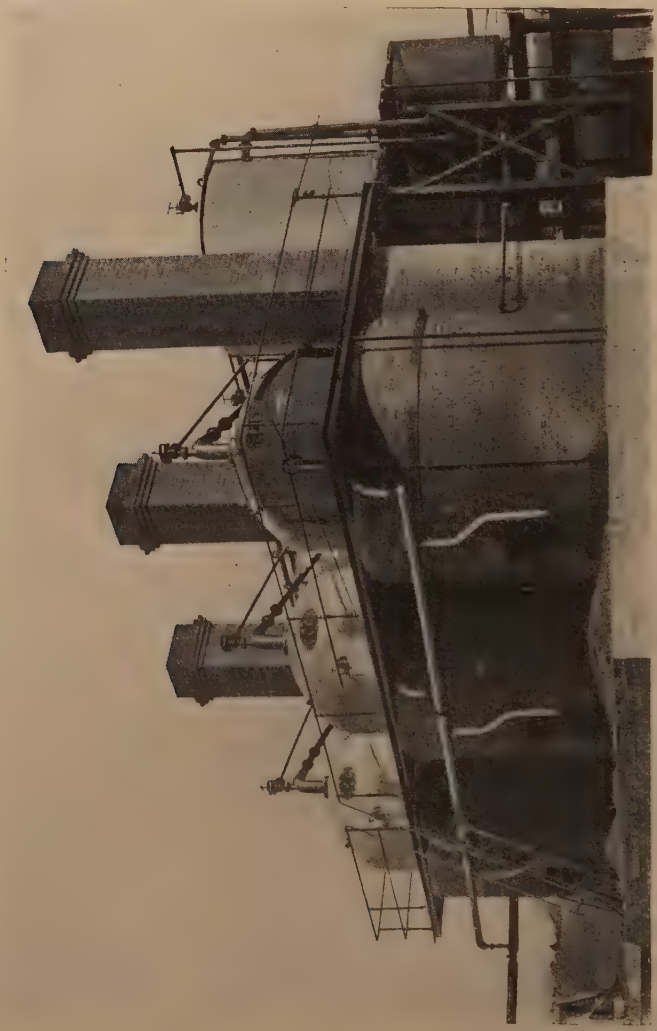
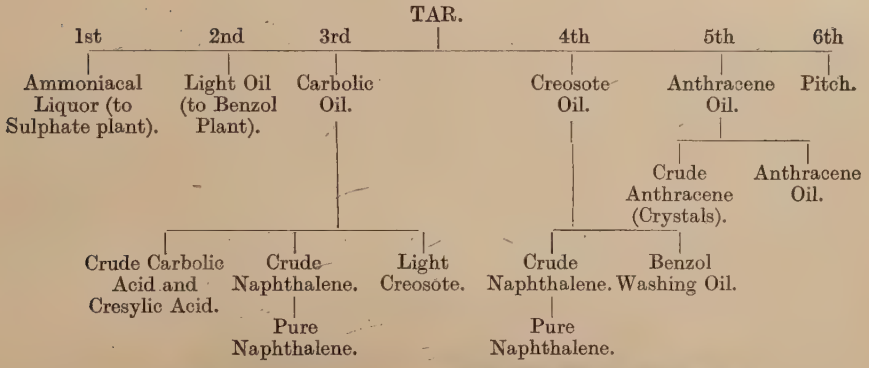


Fig. 205.—View of Tar Stills. (The Abertillery Pitch and Benzol Co., Ltd.)

on the distillation for the extraction of the fine products. The tar is, therefore, generally separated into a few of the cruder fractions, such as ammoniacal liquor, light oil, carbolic oil, creosote oil, anthracene oil, pitch. The fractions recovered from the tar in an ordinary sized plant may be as follows:—



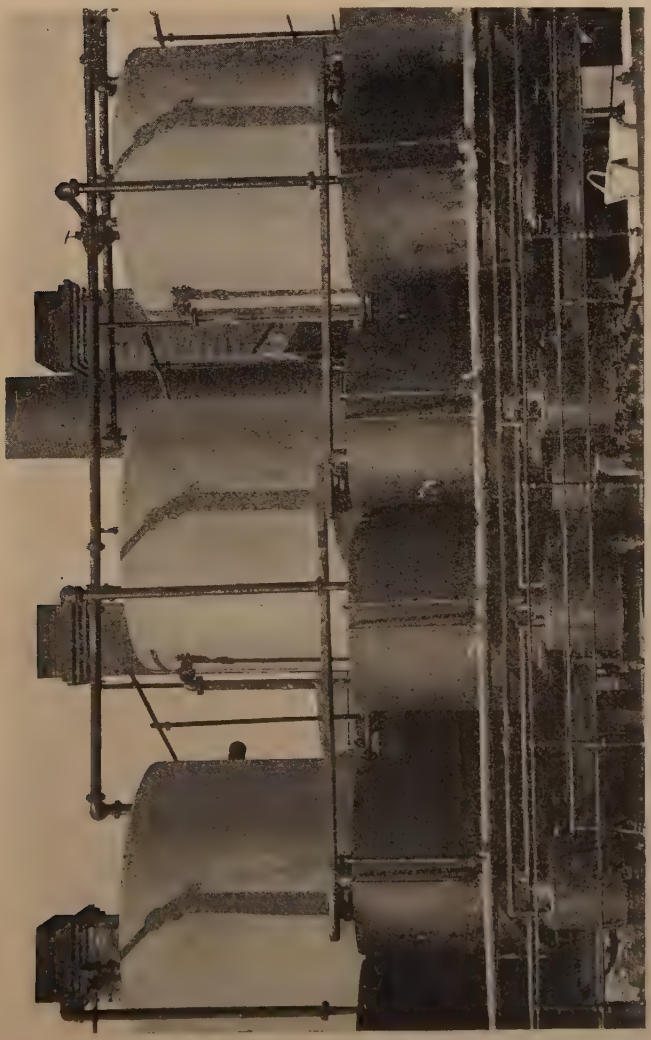


Fig. 206.—Preheaters and Condensers for Tar Stills.

Messrs. Coppée have erected a modern tar distillation plant for the Abertillery Pitch and Benzol Co., Ltd., at Lower Pontnewydd, S. Wales. Figs. 205, 206 and 207 show views of this installation, which consists of pre-heater, tar stills, pitch cooler, light oil and heavy oil condensers, collecting and separating boxes, pitch bays, product storage tanks, steam boiler, and chimney stack, with the buildings and pumps, oil and gas mains, oxide purifier, and other accessories. The stills are fired by gas from the coke ovens where this is available, but the plant shown in the illustration is fed with coal or coke. Fig. 205 shows a general view of the tar stills ; fig. 206 is a view of the pre-heaters and condensers, and fig. 207 a general view of the complete plant.

In a plant of this description, as planned by Messrs. Coppée, the tar is first pumped up from the storage tank into the dehydrating still B, fig. 207, where it is gently heated by the vapours leaving the tar still C ; this preliminary heating of the tar is for the purpose of getting rid of the ammoniacal liquor, together with a portion of the light oil which comes over with the liquor ; these vapours are conducted away through the swan-neck pipe to the condenser D ; the condensate is then passed through the pot E, where the oil is separated from

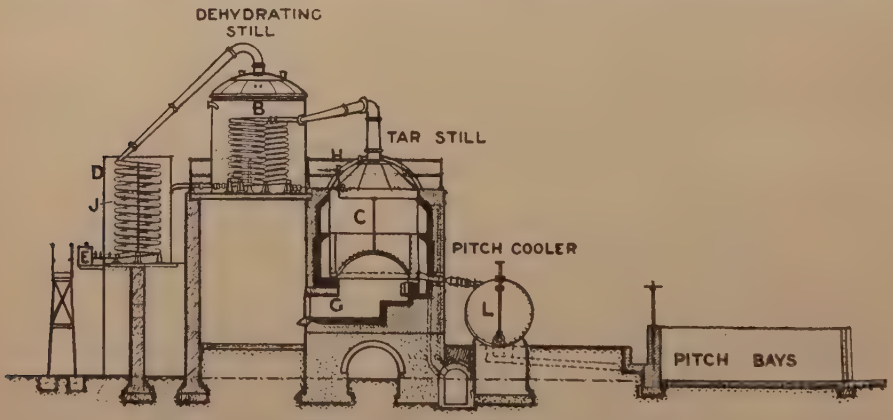


Fig. 207.—Section through Tar Still and Pitch Bays.

the ammoniacal liquor, and each is then allowed to flow into its respective receiving tank. The tar, now dehydrated, is run by gravitation from the still B, into the tar still C, after which the still, B, is charged with fresh crude tar. The tar still, C, is heated by the furnace G, in which any low-grade fuel can be used, or coke-oven gas ; during the latter part of the period of distillation the heat from the fire is slackened and steam is introduced into the still through the steam mounting H. The introduction of steam tends to shorten the period of distillation, and at the same time, as has been observed previously, helps to clear the bottom of the still, and thereby preserve the plates from overheating by the accumulation of hard coke pitch. The vapours from the still are collected by the swan-neck pipe and conducted away to the coil in the condenser J, but on their way they pass through the primary coil in the dehydrating still B, giving up their heat to the crude tar, and in this coil the condensation of the vapours first commences. At the outlet of the condensers is fixed a collecting box, where numerous outlets are arranged for distributing the products to their respective storage tanks. Connections to the separating pot E, fig. 207, and the crude gas main, are also provided. After the distillation

is completed the pitch is run off into the pitch cooler L, where it is allowed to remain for some time, after which it is run into the pitch-bays, and there allowed to solidify. The foregoing is shown here as a typical plant for this purpose; plants of a similar construction are built by other makers with almost the same details.

Ammonia.

One of the most important by-products obtained in the process of the carbonisation of coal is ammonia, both as liquid and as sulphate. Both are important materials used in the arts and agriculture, and the demand for both seems to keep pace with the production.

The presence of nitrogen in coal has been a subject for diverse opinions as to its origin, whether it has been the result of vegetable or animal decomposition, or perhaps both combined. The amount is enormous, but all the nitrogen contained in coal is not always capable of being converted into ammonia in the process of carbonisation; some coals during carbonisation give off the nitrogen unchanged, but in most cases it can be recovered as ammonia.

Ammonia is usually present in the liquors that pass over from the retort or coke oven, and is recovered from the hydraulic main, the condensers, and tar extractor, whilst the ammonia uncondensed in the gas, if kept above the dew point through this preliminary apparatus, is extracted by passing the gas through sulphuric acid, when the ammonia takes up sulphur and oxygen, and a precipitate is formed which is recovered as ammonium sulphate. The process is very simple and easily arranged; the chief obstacle in the way of producing the best sulphate is the presence of tar, due to the imperfect removal of this matter from the gas previous to its treatment with acid to form sulphate; but when the gas has been perfectly stripped of every vestige of tar, the production of pure white sulphate of ammonia is a simple chemical process, and is performed without trouble in the most modern plants. The perfection of this process of making pure white sulphate, together with economical working and the lowering of the costs by establishing efficient plant, has been the main object in the development of this industry.

The amount of nitrogen in coal varies from 1 to 2 per cent., and generally as the oxygen in coal decreases the nitrogen increases; if the above percentage of nitrogen is not obtained from coal, it is due to the way the coal is consumed generally; probably 90 per cent. of the valuable chemical, ammonium sulphate, is wasted, and not until coal is treated for by-products, before used either for the domestic fire or for other purposes, will this amount of loss be recovered. However, progress has been made in this direction in recent years by the recovery of these products from coke ovens and blast furnaces, especially the latter, using hard coal such as Scotch splint coals. It has already been stated above that of the 1 or 2 per cent. of nitrogen in the coal a comparatively small proportion is actually recovered by the process of carbonisation, according to W. Foster.* From the 100 per cent. of nitrogen in the coal, by a laboratory experiment, he obtained :—

14·50	per cent.	as Ammonia.
1·56	„	as Cyanogen.
35·26	„	in the Elementary Condition (as part of coal gas).
48·68	„	remaining in the coke.

* *Journal Chem. Soc.*, xiii., p. 105, quoted by Lunge, "Coal Tar and Ammonia," p. 709.

The nitrogen seems to have a great affinity for the carbon in the coal, and that remaining in the coke seems to be irrecoverable commercially, but the fact remains that the longer the period of carbonisation is continued the greater is the yield of ammonia; therefore, proportionally more ammonia is obtained from the same weight of coal in the manufacture of metallurgical coke than is obtained in the manufacture of lighting gas, where the coal undergoes a shorter period of carbonisation. Lunge quotes the following :—

I.—100 Parts of Coal contained—								
Nitrogen.	Westphalian.	English (Bolton).	Silesian.	Bohemian.	Saxon.	Saar.	Bohem. Cannel.	Bohem. Brown Coal.
Total,	1·50	1·45	1·37	1·36	1·20	1·00	1·49	0·52
Left in coke,	0·96	1·02	0·95	0·77	0·86	0·85	0·56	0·23
Volatilised,	0·54	0·43	0·42	0·59	0·34	0·21	0·93	0·29
II.—100 Parts of Nitrogen reappeared—								
In the coke,	80	72	70	69	64	57	44	38
Volatilised,	20	28	30	31	36	43	56	62

Several attempts have been made to increase the yield of ammonia, but none as far as the author can ascertain have been able to extract the ammonia from the coke without destroying the latter. Messrs. Young and Beilby proposed, B.P. 5084, 1882, to obtain a large proportion of the ammonia from coal dross, shale, or peat, by a process conducted in heated retorts, where the carbonaceous matter is consumed in an atmosphere of air and steam, with the production of gas for heating purposes, and containing the ammonia and water vapour. After the gas has been cooled and the ammonia absorbed by sulphuric acid, it is taken away for heating purposes. It is claimed by this process that about 70 to 80 per cent. of the nitrogen in the coal is obtained as ammonium sulphate. The gas is very much richer than ordinary producer gas, as the following comparative analyses will show :—

	Wilson Gas.	Young and Beilby Gas.
Carbon dioxide,	7·14	15·40
Hydrogen,	12·15	34·53
Carbon monoxide,	19·83	10·72
Methane,	3·91	4·02
Nitrogen,	57·24	35·33
	100·27	100·00

The principles propounded by these inventors, presumably in the first instance for treating shale, are described in detail in B.P. 1578, A.D. 1880, B.P. 1587, A.D. 1881, where several forms of gas producer and several arrangements of gas retorts are used for carrying out the process. In one form of

apparatus, B.P. 5084, 1882, we have a vertical retort constructed of brick, the top of which is closed by a gas-tight door, and provided with an exit pipe for the gas, which is carried away to the condensers; at the bottom of this retort is a fireplace and ashpit, closed; the ingress of air is regulated by means of dampers. The retort is heated from the outside by flues which surround it. The charge of coal or shale is inserted at the top door, and steam is applied lower down in the region of incandescent coke; the steam is partly decomposed, forming hydrogen and carbon monoxide gas, and freeing the ammonia, which passes away with the volatile products to the condensers; any coke not consumed by the action of the steam, which must be large in amount, passes further down, on to the fire grate, where it is completely gasified by the admission of air in regulated quantity, which converts the coke into CO gas, which escapes by ports at the lower end of the retort into the flues, to be there burned to heat the retort. The gases obtained from the upper portion of the charge after giving up their ammonia are returned to the flues for the same purpose. The gas produced, therefore, is very rich. It is questionable whether this process would be a commercial success with coal, unless conducted upon a large scale in a district where the gas could be profitably used; but, can this rich gas be produced to any large extent with the maximum quantity of ammonia? It will be obvious that the reaction of steam on the incandescent coke to produce hydrogen is highly endothermic, the coke being very soon cooled down to such an extent that water vapour is produced if not very carefully watched and controlled, and instead of gas rich in hydrogen, carbonic acid will result, with an increase of ammonia. The two reactions are not homogeneous, the one requiring a high temperature, and the other a low temperature for its proper course; for example, $C + H_2O = CO + H_2$ requires a high temperature, approximating to 1,000° C., but, as stated, this reaction is not stationary, but is continually causing the temperature to fall, by the absorption of heat in the hydrogen produced, so that when the temperature falls to, say, below 850° C., the reaction $C + 2H_2O = CO_2 + 2H_2$ ensues; however, it is a fact that the latter reaction is the more favourable for the production of ammonia. L. Mond, B.P. 3923, A.D. 1883, and B.P. 8973, A.D. 1885; B.P. 12,440, A.D. 1893; B.P. 16,781, A.D. 1895; B.P. 28,588, A.D. 1896, works out the same reactions for producing ammonia by an excess of steam. Fig. 208 shows a section of the producer designed by him for the production of gas and ammonia, and consists of a hopper containing the coal placed above the producer; from this hopper the coal is charged into the producer bell in charges of from 3 to 10 cwts. each; the coal is here subjected to the preliminary heating in order to gasify the tar, which together with the volatile products in this preliminary distillation passes down into the hot zone of the producer, where it joins the bulk of the gas leaving the producer. The coal after this heating passes further down into the zone of combustion, where it is acted on by a blast of air saturated with steam at 85° C., and superheated before coming into contact with the fuel. The amount of steam blown into the producer with the air blast is about $2\frac{1}{2}$ tons per ton of coal gasified; of this amount about half a ton is decomposed by the incandescent coke, producing hydrogen gas and carbon monoxide; the undecomposed part of the steam passing through the producer is claimed to be recovered and returned to the producer. The steam entering with the blast keeps down the temperature of the fuel in the producer and prevents the formation of clinker. The hot gas and undecomposed steam leaving the producer pass through a tubular regenerator in the opposite direction to the incoming air blast, exchanging heat with the blast, which is

further heated in passing down the annular space, *d*, of the producer on its way to the water-sealed fire grate. A certain proportion of waste furnace gases is introduced with the blast, the CO_2 in which is decomposed and joins the other gas in the producer; this also tends to lower the temperature in the producer.

The hot gases from the producer are passed through a washer, the tar and ammonia being condensed, or the ammonia may be collected without cooling the gas; where this is done the gas passes up through a lead-lined tower filled with tiles, presenting a very large condensing surface, and where it also meets a downward flow of very weak sulphuric acid, circulated by pumps, and containing ammonium sulphate, with about 4 per cent. excess of free acid. As the gas

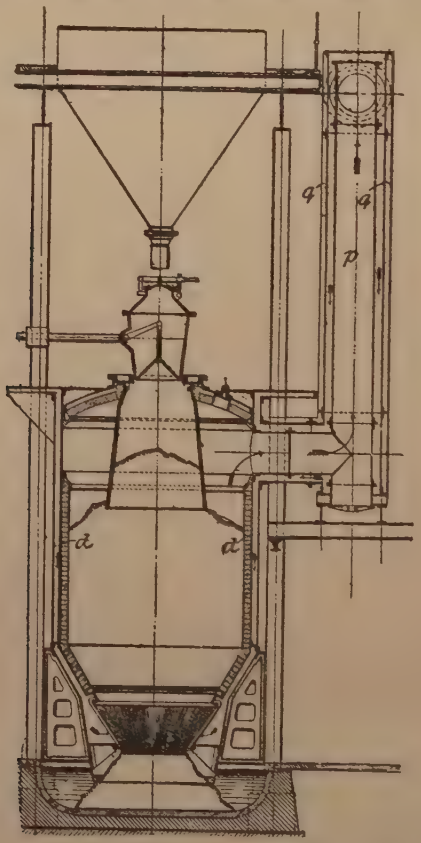


Fig. 208.—Vertical Section of Producer for "Mond" Ammonia Apparatus.

comes in contact with the free acid additional sulphate is produced, and in order to ensure the process being a continuous one, a portion of the ammonium sulphate liquor is constantly withdrawn and evaporated down to solid ammonia sulphate, while a portion of free sulphuric acid is constantly added. The gas, after the ammonia has been recovered, is conveyed in pipes for use in gas engines or for other purposes. The following figures are typical of the materials used and obtained in a Mond gas plant, recovering the sulphate :—*

* "Mond Gas, its Production and Application," A. Rollason, 1901, p. 11.

	Slack as Received. Per cent.	Calculated on Dry Slack. Per cent.
"Average analysis of fuel (by weight) :—		
Moisture at 212° F.,	8·60	Nil.
Volatile matter (excluding carbon),	18·29	20·01
Total Carbon,	62·69	68·59
Ash,	10·42	11·40
	100·00	100·00

	Per cent.
Analysis of ash leaving the producer :—	
Ash on dried sample, by weight,	87·0
Carbon,	13·0
Total carbon lost in ash, calculated on the fuel used,	5·31
Carbon available for conversion into gas,	57·38

Calorific value of the fuel (tested on dry sample) :—Determined by combustion in compressed oxygen in a bomb calorimeter, B. T. Units per lb. = 11·164.

	Volume per cent.
Analysis of Mond Gas (Dry) :—	
Carbon monoxide (CO),	11·0
Hydrogen (H_2),	29·0
Marsh gas (CH_4),	2·0
Carbonic acid gas (CO_2),	16·0
Nitrogen (N_2),	42·0
	100·0

Weight of 1 cubic metre (35·32 cubic feet) of dry gas at 32° F. = 1,020 grams (2·24 lbs.)
Weight of 1,000 cubic feet of dry gas at 32° F. = 63·66 lbs.
Specific gravity of Mond gas (Air = 1) = 0·7882.
Each lb. of (moist) fuel gasified yields 59·24 cubic feet of dry gas at 32° F., and 63·54 cubic feet of gas saturated at 59° F.
One ton of moist fuel gasified yields 142,069 cubic feet of gas saturated at 59° F.
Calorific value of Mond gas (products cooled to 64° F.) saturated at 59° F. :—1 Cubic foot in British Thermal Units = 146·0.
Calorific value of total gas made as a percentage on the calorific value of the total fuel gasified = 84·1 per cent.
Combustion of Mond gas and air :—
One volume of gas requires for perfect combustion 1·15 volumes of air.
Theoretical temperature of combustion of Mond gas in air, both being at 59° F. before combustion = 2932° F.

Quantity of material entering the Mond gas producer per lb. of fuel gasified :—		
Fuel	Dry slack,	0·914
	Moisture,	0·086
Steam	From air-heating tower,	0·841
	Extra steam added,	1·332
Air,		2·527
	Total,	5·700
Steam decomposed in producer,		0·531
Mond gas leaving the producer,		3·763
Ammonia recovered, approximately,		0·004

For the above calculations the case has been taken where the extra steam required for the producer blast can be found in the form of exhaust or waste steam. The figures will remain practically the same if the steam is raised by utilising the waste heat from the gas engine exhaust gases. In cases where this extra steam has to be raised in special steam boilers, its cost must be added

to the cost of sulphate, which then becomes about half the value of the sulphate recovered.

The chief object in the Mond process is the production of ammonia, and the enormous amount of steam, with the limited supply of air to the producer, will no doubt give results as tabulated above, but the gas is exceedingly poor, and cannot be used economically in small gas engines. The process has now been in operation for over 20 years, and has not had the universal application that was originally anticipated; no doubt the poor quality of the gas produced, together with the ponderous and expensive plant required, have been the chief factors in its not having been more extensively employed.

Ammonia is now obtained from blast-furnace gases, together with the tar; several processes have been devised, and some have been successfully worked for this end; among the principal are :—

Dempster's	process,	B.P. 11250, A.D. 1884.
Neilson's	,,	B.P. 440, A.D. 1882.
Addie's	,,	B.P. 4758, A.D. 1882.
Chapman's	,,	B.P. 6406, A.D. 1884.
Galbraith and Main's	,,	B.P. 10448, A.D. 1884.
Alexander and M'Cosh's	,,	B.P. 4117, A.D. 1879; 1433, A.D. 1880; 3785, A.D. 1887.

Taking the last-mentioned process first, since it was the first plant erected to treat blast-furnace gases, it was designed by Messrs. Alexander and M'Cosh, and erected at the Gartsherrie Ironworks of Messrs. Baird & Co., where the gases from eight blast furnaces were treated for the recovery of ammonia; the amount of coal consumed per day was between 450 and 480 tons, and the gas produced approached 8,000,000 cubic feet. The gas was collected into a large main pipe 7 feet in diameter, provided as in all cases of furnace gases with dust-collecting boxes; the gas was passed into the condensers, which consisted of a series of large pipes 30 inches in diameter erected in a vertical position, and arranged in twenty rows of ten pipes, each of which was connected alternately at the top and bottom by a cross pipe; a kind of longitudinal box was formed, containing diaphragms, which compelled the gas from one vertical pipe to ascend the next pipe, and so on, the diaphragms having a water seal of about 7 inches in the box. The gas entered this condenser at a temperature of about 400° F., and was cooled down in traversing the twenty tubes to 120° F. A water spray system was applied in warm weather to the exterior of these tubes to ensure the proper cooling of the gas. The gas passed from these atmospheric condensers to the water condensers, which consist of a large chamber divided into several compartments, with openings in the divisions alternately at the bottom and the top. These chambers were crossed by a large number of cast-iron pipes connected at their ends outside by bends, so that a current of cold water was constantly kept flowing through them; the gas passed from one chamber to the next, up and down, among the cold water pipes, and was thus further cooled to 60° F. The cooling surface in these two condensers was calculated to be about $2\frac{1}{4}$ square feet of surface for every 1,000 cubic feet of gas passing through in 24 hours. After leaving this water condenser the gas passed to the scrubbing tower, constructed of iron 80 feet high and 25 feet square, crossed on the inside by a number of sloping perforated plates, down which water was kept continually running. After leaving the scrubber, the gas was exhausted by a set of Root blowers, with an exhaust pressure of about 3 inches of water. The liquor and tar obtained in this apparatus were run into a settling tank, where the tar was separated; the ammoniacal liquor was boiled down in large boilers, while the gas was passed through the saturaters containing sulphuric acid. The yield was

stated to be about 23 lbs. of sulphate of ammonia per ton of coal consumed in the furnaces.

The Dempster process is somewhat similar to that just described; it only differs in some of the details. The gas is passed from the furnaces through large washers consisting of iron boxes with divisions; it passes from one division to the next under the diaphragm forming the division, so that it has to bubble through the water in the box as many times as there are divisions in the box. The box is inclined, so that the tar collected in the bottom may run off.

The Addie process was conducted at the Langloan Ironworks, near Glasgow, and was designed on somewhat different lines to the two former processes. In order to avoid cooling the enormous quantity of gas from the furnaces, the gases were mixed with sulphurous or sulphuric acid, in the form of gas, and obtained by the oxidation of iron pyrites in small blast furnaces erected for the purpose. The mixed gases were first passed through a set of vertical scrubbers where water was kept constantly in circulation, taking up the ammoniacal liquor. The ammonia in the gas was almost instantly converted into ammonium sulphate when the two gases were mixed, the liquor being then worked up into solid ammonium sulphate in the ordinary way. It is stated that this plant was worked most successfully, producing ammonium sulphate of the finest quality.

The Neilson process consisted of passing the gases from the blast furnaces first through a water scrubber; then they were conducted into another chamber filled with earthenware plates, formed with perforations in them, and so arranged that weak sulphuric acid was kept running over them, while the gas passed through and over them; by this means the ammonia was obtained as sulphate at the bottom, from which it was drained off.

Ammonia from Coke Ovens and Gas Works (Coppée Process).—There are two processes for obtaining ammonia from either coke ovens or gas works. The first is the old liquid process with the formation of what is called ammonia liquor; the second is the direct sulphate of ammonia process. There are several kinds of apparatus now in operation to achieve this recovery, constructed by the different firms who build the plants for the recovery of by-products, differing very little from each other, except in details of construction or economical working; one or two examples of these processes may, therefore, suffice to give an idea of the industry as practised in modern installations.

The process of condensing the liquid portions of the distillate from all plants dealing with the distillation of coal, either in the gas works or at the coke oven, provides the ammoniacal liquor. The gas from the retorts or the ovens is first passed by the old process into coolers and the tar extractor; it is then conducted through a series of scrubbers, either static or dynamic, where the ammonia is absorbed by washing the gas with water. The weak liquor so obtained, and containing about 1 per cent. of NH_3, is run into storage tanks, E, fig. 210, with the liquor from the condensers; it is from here pumped into a high level tank, C, fig. 209, then passed from this tank into the decomposer, D, fig. 209, where it is treated with steam, in order to remove the impurities such as sulphur and carbon dioxide; from here the liquor is passed into the stills, E, fig. 209, where it is subjected to steam and the action of milk of lime, which liberates the ammonia and takes out the last traces of sulphur. The vapours from the stills are passed into the reflux condenser F, where the surplus water is condensed and returned to the stills; the vapours then enter the condenser G, where they are brought up to a concentrated form of liquid containing 25 per cent., or up to 30 per cent. of ammonia, which is stored in the tank, H. Should sulphate, however, be required, this is recovered without any alteration of the plant, by simply diverting the

ammoniacal vapours from the still direct into the saturater, fig. 210, where they meet with sulphuric acid and form ammonium sulphate. The process for the recovery of ammonium sulphate is illustrated in fig. 210. The gas from the ovens after passing through the coolers, A, is exhausted by the exhauster B, and driven through the tar extractor C, then through a series of scrubbers D, where the ammonia is thoroughly washed out of the gas; the liquor containing the ammonia is run into the storage tank E. The condensates from the tar extractor and coolers are run into a separate tank F, where the tar is separated from the ammoniacal liquor, and makes its way into the tar storage tank G, and the liquor into the tank E; from here the liquor is pumped into the tank H, from which it flows to the still J. In this still the liquor is treated with steam to liberate the free ammonia, and after this operation it is passed into the still, K, with steam and milk of lime, in order to expel the "fixed" ammonia. The ammonia vapours then pass into the saturater, L, to form ammonium sulphate.

This indirect process for the production of ammonium sulphate is not so advantageous as the later process to be subsequently described, because there is, firstly, the production of a large amount of water, which in certain cases cannot be conveniently disposed of; secondly, there is the expensive process of condensing and cooling; large stills are required, and the cost of raising steam to conduct the process for distillation is high.

Direct Process for Recovering Sulphate of Ammonia (Coppée Process).—This process of the direct recovery of ammonia as sulphate is illustrated in fig. 211. The gas is cooled in the tubular coolers A, where its temperature is reduced to about 25° C., in order to remove a large amount of tar, after which it is drawn by the exhauster B, and passed through the rotary tar extractor C, where the tar is completely removed. After the tar has been thoroughly eliminated the gas is conducted through the main pipe, D, direct to the saturater E, where the ammonia is converted into sulphate by the combination with sulphuric acid, forming crystals which are heavier than the liquid, and which by precipitation fall to the bottom, whence they are extracted by an ejector, worked by means of steam or compressed air. The saturater is completely enclosed, and the process of sulphate formation is continuous, the salt being delivered on to a draining table F, and from there into the centrifugal dryer G, where it is completely freed from the mother liquor; it is then removed by a mechanical conveyer to the sulphate store H. There is, however, a certain amount of ammoniacal liquor produced in the coolers and tar-extracting processes which has to be dealt with, and this is taken from the storage tanks J, and distilled in the stills K, where the ammonia is evaporated by steam and with lime, and the liquor then passed to the reflux condenser on the top of the still; then it joins the other gas in the main pipe at L, fig. 211, by which means the whole of the ammonia in the gas passes into the saturater to form sulphate. When the gas has thus been deprived of its ammonia, it is passed through a lead-lined separator M, in which any acid that may have been carried forward with the gas may be arrested and extracted, previous to the gas passing to the benzol recovery plant. Fig. 212 is a view of the coolers and scrubbers.

Koppers' Process.—Brunck, in Germany, was the first to obtain sulphate of ammonia direct from the gas, but his sulphate was of poor quality. The process had difficulties to encounter, such as the complete elimination of the tar, and the corrosive action of the gases on the plant; he subsequently introduced an apparatus for the mechanical separation of the tar from the hot gas as it came from the ovens, but found this impracticable while the gas remained at a high temperature, which was necessary for the production of ammonium sulphate;

it was then tried to reduce the temperature to facilitate the removal of the tar, but the failure to produce the sulphate on reduction of temperature led to the abandonment of the process. Heinrich Koppers took up this idea, and as a result of his experiments he developed two processes for the recovery of the sulphate. By the first process, B.P. 20,870, A.D. 1904, and B.P. 2399,

Fig. 212.—"Coppée" Condensers.

. 1908, and B.P. 13,327, A.D. 1910, the gases are cooled down to a tem-ature a little above dew point, and then are conducted directly into the)huric acid saturater. Koppers states in his 1904 specification, "The dew nt for retort gas was 72° Celsuis, that of coke-oven gas 85° Celsius (barometer 760 millimetres). This difference arose from the higher percentage of water

in the coke oven gas, as coking coal in contradistinction to gas coal is treated with a certain amount of water (say 14 per cent.)." Coke oven coal is generally washed slack coal, and contains the undrained water from the washery, whereas the coal put into the retorts at the gas works is dry, uncrushed slack coal, as received from the coal pit. He further states, " By the treatment of the raw gas at temperatures which lie slightly above the dew point for separation of water, or at that point, the tar is separated into one part, about 95 per cent. of the whole, which boils above 100° Celsius, and which consequently may be condensed and separated mechanically pure, and into a smaller portion, which remains in the gas in the form of vapour. For the purpose of obtaining the sulphate directly, the gas is conducted into sulphuric acid, or into a bath of acid sulphate lye, which, with the object of obviating any condensation from the gas, is kept at the appropriate temperature ; condensation of the water carried in the form of vapour is prevented, owing to the fact that the temperature of the gas is maintained above the dew point, which has been previously ascertained, so that vaporisation is able to take place even in the acid bath." After separation of the ammonia the gas is cooled to atmospheric temperature, when a soft water becomes deposited for the first time. Koppers states in his 1908 patent that, " in the process described, the temperature of the sulphuric acid bath must be maintained between 105° and 115° C., because the mixture discharged from the battery of stills condenses at nearly 100° C., and should the temperature fall, the condensation of water in this acid bath would become unmanageable and destroy the precipitation of the sulphate. Ammonium sulphate melts at 140° C. ; at considerably lower temperatures decomposition takes place, whereby free ammonia and acid sulphate are formed ; " also particles of the salt escape into the atmosphere and cause an irritation of the mucous membranes, inconveniencing the workmen in the ammonia works. Koppers further states that the affinity between ammonia and sulphuric acid decreases when approaching the temperature of decomposition, especially with solutions which contain a very small percentage of acid ; this affinity finally ceases at the said temperature, as the salt then decomposes. Thus part of the acid is not utilised for binding the ammonia, but remains in its free state enclosed in the salt. " If a watery solution of neutral ammonium sulphate, $(NH_4)_2SO_4$, is heated or boiled, a small portion of the sulphate is decomposed into ammonia, NH_3, whilst an acid-reacting solution is formed by the production of a corresponding small portion of bisulphate of ammonia, NH_4HSO_4. The commercial salt is to be considered as a mixture of neutral ammonium sulphate and bisulphate of ammonia. The free acid contained in the latter determinates the acidity of the commercial salt. Lately, an almost neutral salt is desired by the trade, or one in which not more than 0·2 to 0·4 per cent. of free acid is present ; formerly salts containing 1 to 1·5 per cent. of free acid were satisfactory." Koppers goes on to state that his improved process is effected by " causing the precipitation of the ammonium sulphate at a temperature so far below the normal boiling point of water that decomposition of the neutral ammonium sulphate is impossible while the maximum affinity between the ammonia and sulphuric acid is maintained." He proposes to prevent the premature condensation of water by the mixture of certain gases. " Theoretically, any rarefying gas which remains indifferent during the chemical reaction, for instance, nitrogen may be mixed with the steam." In his 1910 invention he proposes to wash out the fixed ammonia with hot water, which is converted into a salt solution ; the gases are then freed from tar, and passed into a superheating apparatus for the purpose of delivering up their

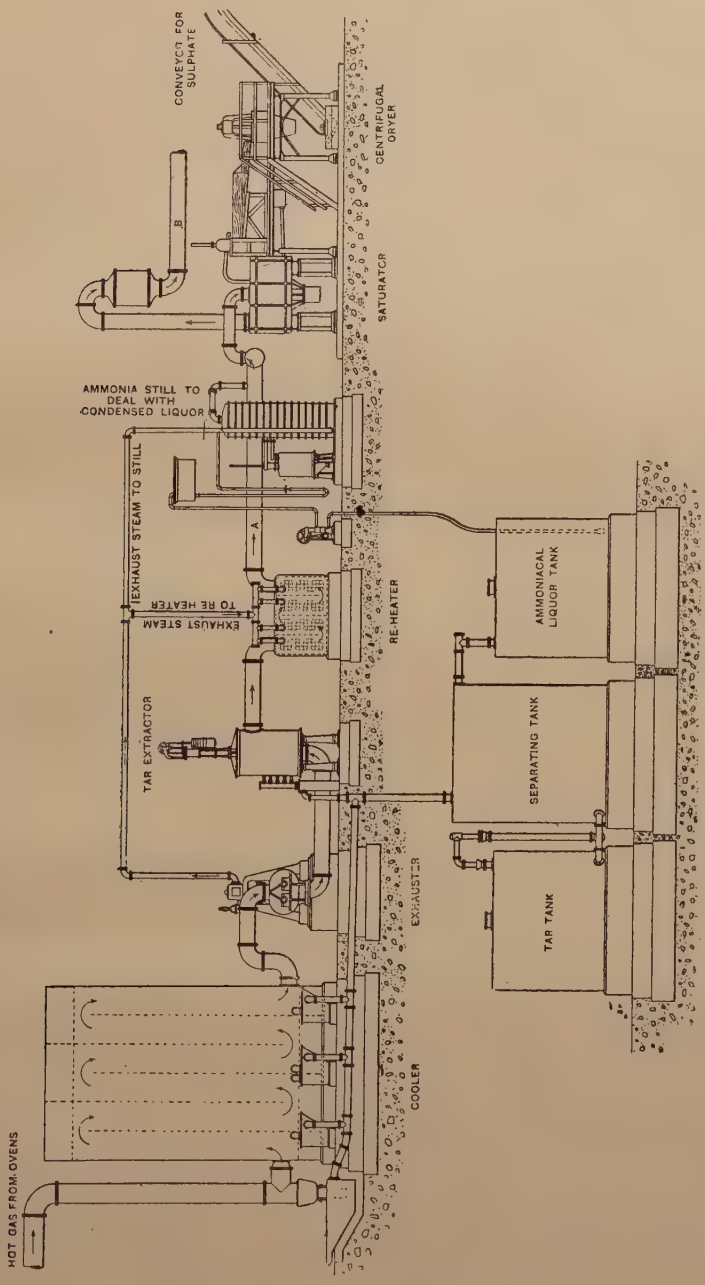


Fig. 213.—Kopper's New Direct Recovery Process.

ammonia in the sulphuric acid saturater. The former processes have been abandoned in favour of the latter process owing to the difficulties encountered in their manipulation. Fig. 213 shows in diagrammatical form the present

process carried on by Koppers Coke Oven and By-Product Co. for the direct recovery of sulphate of ammonia. The hot gas direct from the ovens enters the coolers, where the temperature is reduced to about 23°-25° C., thereby removing by condensation a large portion of the tar. The gas is withdrawn from the coolers by the exhauster and passed into the tar extractor, in which all traces of tar are eliminated; the gas is then introduced to the reheater, where it becomes heated up by means of exhaust steam to a temperature of about 50°-60° C. The heated gas is then passed through the main pipe, A, to the saturater, where the gases are subjected to direct absorption in sulphuric acid and the ammonia recovered as sulphate. The saturater is of the enclosed, continuous working type, the sulphate of ammonia being continuously removed by means of an ejector working with steam or compressed air. The sulphate is by this means delivered on to the draining table, and from thence to the centrifugal dryer, from which it is taken by the conveyer to the sulphate store. The condensed liquors from the coolers and tar extractor, etc. are conveyed to the separating tank, where the tar is separated from the ammoniacal liquor. The tar flows to the tar storage tank, and the ammoniacal liquor is pumped from its storage tank to the high-level liquor tank situated above the ammonia still, from which it flows into the latter, where the ammonia is driven off by means of steam and lime in the usual way. The vapours from this distillation are conducted through a tube and enter the main gas tube A, where the whole of the gases are mixed and passed into the sulphuric acid saturater. There is no live steam whatever used in this process, any steam required for the purpose of distilling the liquor to liberate the ammonia gas therefrom, or for the purpose of reheating the cooled gases, is exhaust steam from the engines driving the exhausters. The gas after leaving the saturater is passed into the benzol plant for the extraction of the benzol contained in it. The most successful feature in this process is in the conditions created by cooling the gases for the perfect elimination of the tar, provided that the tar extractor is designed to meet these requirements, but it must be remembered that, even with cooled gases, the perfect elimination of every particle of tar is not so simple a problem as it appears; with the best apparatus for this purpose close attention is required to ensure its efficient working. It is further claimed in this process that at a temperature of 25° C. the naphthalene content at saturation is 56 grams per 100 cubic metres, whilst at a temperature of 50° C. it is over 500 grams per 100 cubic metres; by thus cooling the gas, and allowing it to have contact with comparatively cold tar, the naphthalene is removed and passes into the tar, whereas when the gas is kept hot the naphthalene is not condensed into the tar, but remains in the gas, and is passed forward, causing trouble in the mains and apparatus. Koppers, in his criticisms of other processes, anticipates trouble with ammonium chloride present in the gases which have not been cooled in the process for tar extraction, maintaining that the liquors produced in the coolers carry away the ammonium chloride, which is dealt with separately in their process, whereas if this salt is carried forward with the gases, it is decomposed by the action of sulphuric acid, hydrochloric acid being liberated, passing forward with the gas, and causing the apparatus through which the gases pass to become corroded; any ammonium chloride not so decomposed remains in the saturater, and is carried out with the sulphate, thereby contaminating it. In this process the firm maintain that only about 50 per cent. of the water produced by the old process is found in the effluent liquor, while in the processes of other firms using what is termed the "hot process," no effluent liquor is produced; this is questioned by Koppers, who states that, unfortunately, this claim cannot be substantiated,

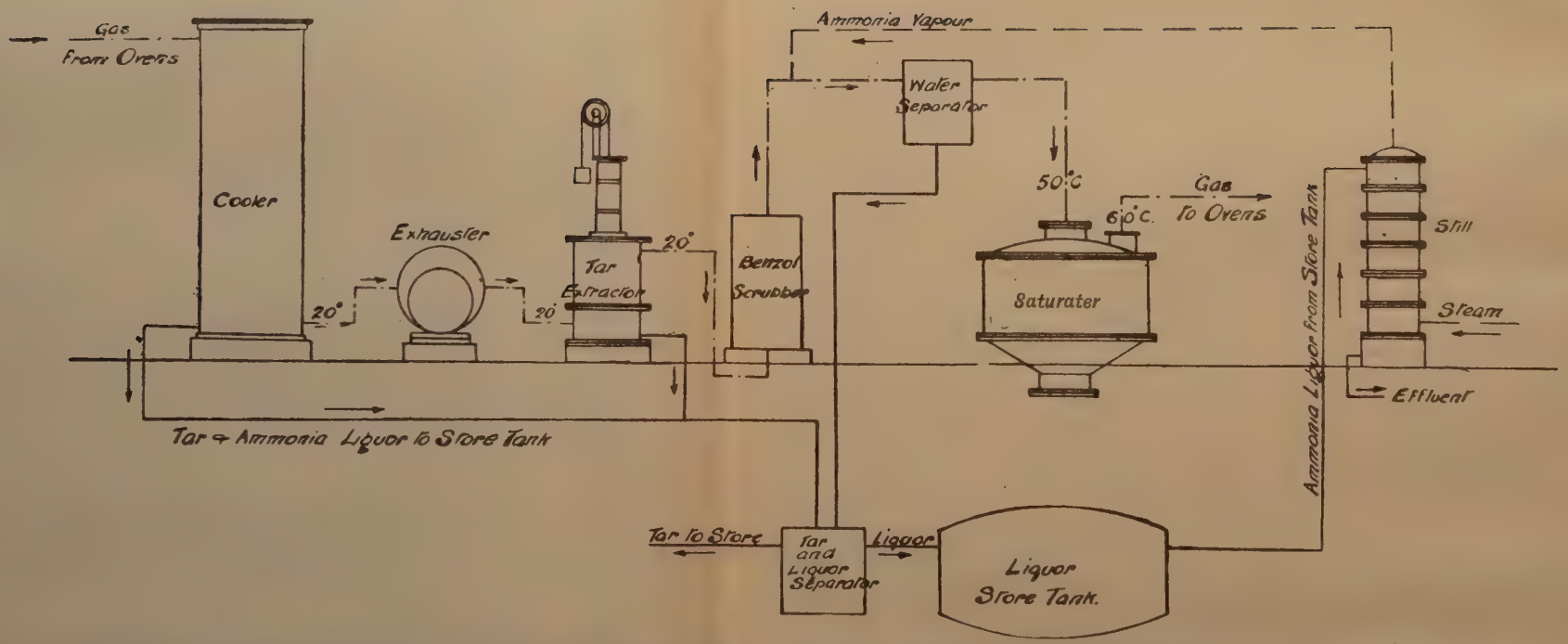


Fig. 214.—Diagram showing arrangement of New Direct-Recovery Process, with Benzol Scrubber, as installed at Beighton Colliery. ("Semet-Solvay.")

and further states that, " The production of effluent liquor can only be avoided when dry coal is carbonised, and where benzol is not recovered." (?) In comparing their process with the " hot process," the firm state that the following disadvantages of that process are overcome by their process, viz. :—

" 1. Powerful pumps required to spray the tar under pressure into the gas.
2. Tar not effectually removed, and hence a dirty salt produced.
3. At least double the power required for driving the exhausters.
4. Additional heat required for evaporating the liquor containing the fixed ammonium salts.
5. Steam required for maintaining temperature of liquor in saturater.
6. Heat required for evaporating the liquor condensed out of the return gases to the ovens.
7. Interruptions of working owing to deposition of naphthalene in mains.
8. Corrosion of pipes and apparatus through liberation of hydrochloric acid in saturaters.
9. Loss of ammonia from the fixed ammonia compounds when tar is extracted above the dew point of aqueous vapour.
10. Loss of heat in raising steam in gas to chimney temperature."

The Coke Oven Construction Co., Ltd. (Semet-Solvay) Process.—A new direct ammonia recovery process, which in its main details also resembles the other processes, but has some new distinguishing features, is used by the Coke Oven Construction Co., Ltd. This new process may be carried on with or without the introduction of a benzol scrubber. Fig. 214 illustrates an installation with a benzol scrubber.

The company point out certain of the difficulties of the " hot process " enumerated by Koppers, and maintain that they have overcome them by other means than those adopted by Koppers. Their process is as follows :—They state that when the direct process is essential (as, for instance, where no means are found for the disposal of the waste liquors) the gases are taken from the ovens and collected in a " tar main," and no liquors are circulated. On leaving this main the gases pass through an apparatus for regulating temperatures, and are afterwards washed with tar in a series of bubbles, B.P. 7915, A.D. 1910. The gases, after passing through the tar separator and still at a temperature above the point at which water is deposited, are then bubbled through sulphuric acid, where the ammonia is recovered in the form of sulphate, which is periodically ejected from the saturater, dried, and transferred to the sulphate store. In this process they state that where effluent liquors cannot be got rid of, the recovery of benzol must be sacrificed ; if, however, these liquors can be disposed of, the gases freed from ammonia can be cooled to condense the aqueous vapour, and washed with the absorbing oil to recover the benzol. They also state, " Troubles have been experienced with this form of the ' direct ' or ' hot process,' due to the formation, for example, of naphthalene on cooling, and the deposition of fixed ammonium salts in the tar and gas main pipes, and to a considerable amount where coals containing a high proportion of the ammonia as chloride have been carbonised, although the fixed ammonia as chloride is recoverable if the proper means are applied for its extraction; but as the demand for chloride of ammonia is very limited, it is more desirable to avoid producing it. To avoid the difficulties by which such a process is attended, a new process was devised by this firm for the direct recovery of ammonium sulphate, in which the gases after leaving the ovens are cooled to the point at which the tar and water (containing part of the free ammonia, and all the fixed portion) are deposited. The ammoniacal liquors that are condensed from this part of the apparatus are distilled with lime in the usual way, and the vapours of ammonia thus freed are delivered into the main pipe, with the

other portion of the gases going forward to the saturater. The gases from the cooler are drawn forward by the exhauster through the tar extractor, where the tar is eliminated, and then passed direct to the saturater. The hot gases from the distillation of the ammoniacal liquor are mingled with the cooler gases from the tar extractor, and raise the temperature of the total gas approaching the saturater, so that they enter the saturater at or about 50° C.; but until the gases so mixed find their equilibrium temperature, there is a certain amount of condensation produced; the mixture of gases produce a certain "water fog" corresponding to the amount of saturation, and unless means are adopted to deal with this, the condensation would occur when the gases entered the saturater, weakening the acid bath, and destroying its efficiency in depositing sulphate. The method of obviating this is to place a condenser or "dryer" in between the still and the point where the gases enter the gas main pipe from the tar extractor, as seen in fig. 214, designated the water separator. In this system the ammonia vapour is led direct from the still into the gas main, where it mixes with the gases, and the "water fog" is trapped by the above-mentioned water separator, and condensed, the gas passing thence directly into the saturater. This arrangement also fulfils another purpose besides condensing the "water fog," in that it separates the traces of tar that are carried forward, and that have not been completely taken out by the extractor, together with the light oil and other impurities that may influence the sulphate deleteriously; the result is that the gas being now completely purified, the sulphate produced is a pure white salt.

Where benzol is recovered in the semi-direct method, the practice is to cool the gases after the ammonia has been abstracted in the saturater, and before they enter the scrubbers; but, to avoid a second condensation apparatus, the arrangement installed at the Beighton Colliery is stated to be giving excellent results; the benzol scrubber is placed between the two extractors and the ammonia saturater. It is claimed that "this process has the advantage that considerably less liquid is treated in the distillation column per unit of gas made than in the other processes, while the gases are not superheated and no cooling or concentration of the ammonia vapours is required, and owing to the gases passing through the saturater being in a purely saturated state, the process is less dependent upon the ammonia content than in the case with gases passing through the saturater in a supersaturated state; the gases are also not scrubbed with water to recover the ammonia as in the old process, and there is, therefore, a smaller quantity of ammoniacal liquor to be distilled."

The Otto Process.— In the Otto direct process for recovering the ammonia the hot gases from the ovens are led away from the hydraulic main to an air cooler, and any tar or liquor condensed in the hydraulic main is caught in the "tar catch tank." The cooler is used as a regulator to cool the hot gases down to a little above the dew point, the required temperature varying according to the quantity of moisture the gas is carrying. From the air cooler the gas passes on to the spray tar extractor, fig. 188, described in the previous part of this chapter dealing with tar extraction; it is here met by a large volume of tar and liquor, which is pumped in under a high pressure, and sprayed by being forced through the narrow neck of the injector along with the hot crude gas. The sprayed tar and liquor dash against the small tar vesicles contained in the hot crude gas, and by this means the tar is precipitated. The tar thus collected overflows into the above-mentioned "tar catch tank." The gas now having been freed from the tar passes into a large saturater of the enclosed type containing weak sulphuric acid.

I. Table showing the Properties and Composition of Eight Samples of Gas-liquor, obtained from the Same Coal, but taken from Different Points in the Condensing and Scrubbing Plant.*

	Condensed in Hydraulic Main.	Another Point in Hydraulic Main.	Liquor from First Condenser Column.	From Second Condenser Column.	From Third Condenser Column.	From Fourth Condenser Column.	From First Washer.	From Finishing Washer.
Colour,	Very dull orange, turned black in air.	Very dull orange, turned black in air.	Colour-less.	Almost Colour-less.	Brown red from light tar-oils.	Dark brown from tar-oils.	Colour-less.	Colour-less.
Specific gravity in deg. Twaddell at 15·5° C.,	2¼	2½	7	15	23	24	4½	2
Ounces by distillation test,	6·1	6·0	16·2	36·1	53·0	58·0	16·5	8·3
Ounces by saturation test,	2·7	2·8	15·9	35·7	52·5	57·4	16·1	8·1
Amm. sulphide, grams per gall.,	364	440	2430	5000	7905 NH_3	8440	1592	1220
$= NH_3$, ,, ,,	182	220	1215	2500		4220	796	610
Amm. carbonate, ,, ,,	564	510	3384	8120		12126	4512	1690
$= NH_3$, ,, ,,	200	81	1200	2880		4300	1600	600
Amm. thiosulphate, ,, ,,	122	82	Trace	125	352	765	230	135
$= NH_3$, ,, ,,	28	19	Trace	41	81	176	51	31
Amm. sulphate, ,, ,,	8	34	..	..	..	..	..	..
$= NH_3$, ,, ,,	2	9	..	..	..	..	..	..
Amm. sulphocyanide, ,, ,,	112	130	91	Trace	..	..	112	27
$= NH_3$, ,, ,,	25	29	2	Trace	..	..	25	6
Amm. chloride, ,, ,,	1552	1455	119	155	201	107	88	38
$= NH_3$, ,, ,,	493	462	38	50	64	34	28	12
Amm. ferrocyanide, ,, ,,	...	Trace	22	41	125	375	..	..
$= NH_3$, ,, ,,	..	..	5	10	30	90	..	..
Total ammonia, ,, ,,	930	920	2460	5480	8080	8820	2500	1260
Percentage of fixed ammonia in total ammonia,	59	56	1·8	1·85	2·2	3·4	4·2	4·0
Ammonia expressed as cwt. of sulphate per 1,000 gallons,	4·5	4·5	11·9	26·6	39·3	42·8	11·8	6·1
Value of liquor for sulphate making,	Very small	Very small	Very good	Very good	Excellent	Excellent	Very good	Not quite strong enough

* Lunge, "Coal Tar and Ammonia," p. 741.

II. Table showing the Properties and Composition of Various Samples of Liquor from Different Coals and from Different Points in the Condensing and Scrubbing Plant.

	Condensed Liquor passed through Scrubber.	Another Sample taken at Different Time.	Same Liquor exposed to Air, High Temperature.	Hydraulic Main Liquor.	Part Condensed Liquor, Part Hydraulic Main.	From 'Standard' Washer, before Purifiers.
Colour, ...	Yellow	Yellow	Bright Orange	Dull Yellow	Yellow	Colourless
Sp. gr. in deg. Tw. at 15·5° C., .	4·5	4	3·5	2	3	4·5
Ounces by distillation test, .	10·00	8·25	6·90	5·60	6·60	10·00
Ounces by saturation test, .	8·30	7·00	4·25	3·40	4·90	10·00
Amm. sulphide, grams per gall.,	960	1216	630	576	220	1180
= NH_3, „ „	480	608	315	288	110	590
Amm. carbonate, „ „	2030	1156	800	..	1692	2540
= NH_3, „ „	720	410	283·5	193	600	900
Amm. thiosulphate, „ „	195	182	236	..	174	Trace
= NH_3, „ „	45	42	52·5	35	40	..
Amm. sulphate, „ „	..	Trace	39	..	9	..
= NH_3, „ „	..	..	10·5	6	2·5	..
Amm. sulphocyanide, „ „	338	243	472	..	90	..
= NH_3, „ „	75	54	105	36	20	..
Amm. chloride, „ „	567	403	891	..	693	32
= NH_3, „ „	180	128	283·5	301	220	10·1
Amm. ferrocyanide, „ „	Trace	..	..	..	31	..
= NH_3, „ „	..	..	..	..	7·5	..
Total ammonia, . . .	1500	1250	1050	860	1000	1500
Percentage of fixed ammonia,	20	18·3	43	44	29	0·7
Ammonia expressed as cwt. of sulphate per 1,000 gallons, .	7·5	6·00	5·00	4·10	4·85	7·30
Value of liquor for sulphate making, ...	Not good	Poor	Very poor	Not worth working	..	Very good

In this apparatus the gas is divided into a number of small streams by means of the suction developed by the exhauster; it bubbles through the acid, the ammonium sulphate being precipitated to the bottom of the saturater, which has a conical formation, and it is continuously ejected with a certain quantity of the solution by means of compressed air; this is received in another cone-shaped vessel, where the sulphate crystals separate out and descend to the base, while the liquor overflows from the top and runs back into the saturater. When the cone-shaped receiver has received its full complement of crystals, these are passed into the centrifugal dryer. In this machine, running at a great speed, the sulphate crystals are freed from the liquor in about three minutes; the mother liquor taken out by the centrifugal dryer also flows back into the saturater. The dried crystals are then dropped through the bottom of the dryer, in a sufficiently dry state either to be straightway bagged or stored. The gas is now led through a lead-lined catch pot (the design of which prevents any acid spray being carried forward), and on to the naphthalene extractor and spray-cooling tower. This tower is quite empty, having no apparatus or filling in it, but is supplied with a series of jets of cold water which is sprayed at high pressure; by this action, the sudden chilling of the gas and the concussion produced by the water pressure on the gas particles containing the naphthalene, the latter is condensed and practically the whole is washed out and flows

	Ammoniacal Liquors from English Gas-Works.									From Carbonising Works.	From English Coke-Works.			From Blast Furnaces.			From Scotch Shale Works.		From Distilling Bones.
	1	2	3	4	5	6	7	8	9		1	2	3	1	2	3	1	2	
Specific gravity, .	1·020	1·024	..	1·026	1·019	1·025	1·025	..	1·033	1·020	1·030	1·017	1·010	1·005	1·010	1·009	1·016	1·008	1·027
Cyanides, . .	Trace	..	..	Trace	Trace	..	..	Trace	Trace	Trace	..	Trace	..	..	..	Trace	..	..	..
Ferrocyanide, .	..	Trace	..	..	..	Trace	Trace	..	..	Trace	..	..	..	..	..	..	..	..	..
Chloride (as HCl), .	0·006	0·620	..	0·685	0·12	Trace	Trace	Trace	0·946	0·571	0·0716	0·392	Trace	0·233	Trace	Trace	0·022	0·014	0·068
Ammonia (Total), .	1·827	2·630	1·84	2·476	1·382	1·593	1·550	1·316	2·745	1·418	1·542	1·613	0·364	0·162	0·385	0·329	0·980	0·238	1·755
,, (Fixed), .	0·110	0·395	0·28	0·490	0·120	0·100	0·100	0·116	0·600	0·288	0·242	0·239	0·114	0·082	0·019	0·006	0·034	0·037	0·012
,, (Free), .	1·717	2·235	1·56	1·986	1·262	1·493	1·450	1·200	2·145	1·130	1·300	1·374	0·250	0·080	0·368	0·323	0·946	0·201	1·743
Hydrogen sulphide,	0·6256	0·634	0·397	0·629	0·100	0·068	0·064	0·093	0·709	0·567	0·057	0·333	0·0017	..	..	..	0·047	0·0058	0·043
Sulphur (Total), .	0·633	0·6955	..	6·750	0·1366	..	..	..	0·8629	0·6084	0·3754	0·3720	0·1651	0·0021	0·0066	0·0039	0·0927	0·0565	0·0461
Carbon dioxide, .	1·860	2·023	1·39	2·019	1·493	1·819	1·830	1·485	2·365	1·165	2·315	1·170	0·418	0·116	0·755	0·708	1·480	0·396	3·015
Distribution of sulphur %:—																			
as sulphate, .	4·14	0·59	..	0·43	4·03	..	..	..	0·81	3·07	6·47	6·64	37·73	42·86	30·30	38·46	4·53	24·25	12·37
as sulphocyanide,	2·26	7·91	..	14·40	16·47	..	..	..	12·91	5·21	7·04	8·42	16·84	..	..	..	..	..	..
as thiosulphate,	0·55	5·66	..	6·24	10·83	..	..	..	8·94	4·11	72·19	0·71	44·16	57·14	69·70	61·54	47·79	66·02	87·63
as sulphide, .	93·05	85·83	..	78·93	68·67	..	..	..	77·33	87·61	14·31	84·22	0·97	..	..	..	47·68	0·973	0·0461

away with the water into a settling tank situated beneath this apparatus, fig. 215; the naphthalene is then filtered off and the water allowed to run off, to be used again if necessary. As it is necessary to get the naphthalene out previous to the gas entering the benzol scrubbers, the process in this tower serves this purpose, as well as cooling the gases for the subsequent process, preventing the naphthalene becoming dissolved in the recovered benzol. The naphthalene thus recovered is of a pale yellow colour, and readily finds a market, which is stated pays all the costs of running this part of the plant. The gas now being cooled passes through the exhauster, and by the action of a second water cooler all the remaining moisture is condensed and the gas thence passed to the benzol scrubbers. By this invention the temperature of the gases thus lowered is stated to be about 80° C., and this temperature is maintained. By B.P. 26,124, A.D. 1909, this is accomplished by adjusting the amount of flow of the tar and liquor scrubbing spray, which is cold, through the injector, and never allowing this tar and liquor to rise above 80° C., thereby insuring the complete condensation of the tar and the non-condensation of the ammonia in the gas.

The difficulty of ascertaining the real value of ammoniacal liquor from hydrometer observations is shown in the table on p. 361, which proves the inequality of the percentages of ammonia in different gas liquors of the same specific gravity (at 15° C.).* The difficulty is due to the density of the liquor being raised by presence of ammonium salts.

In consequence of these discrepancies it is preferable to estimate the value of ammoniacal gas liquor by the chemical method. Lunge recommends the employment of the standard acid, which contains 0·049 gram H_2SO_4 per c.c., each c.c. being equivalent to 0·017 gram NH_3.

The valuation is made in ounces in England, the test being accomplished by measuring off 16 liquid ounces of the gas-liquor, then from a burette which is graduated to ounces the test acid is run in, until a test with litmus indicates a neutral solution. From the amount of the acid run in, in ounces, the number of ounces of sulphuric acid that are required for each gallon of ammoniacal gas liquor can be calculated. This test is designated the "saturation test," and indicates only the "volatile" ammonia. If the total ammonia, including that which is combined with strong acids, has to be determined, the liquor is distilled with alkali (lime, magnesia or baryta), the vapours being received into a standard sulphuric acid solution, the free acid remaining being subsequently determined by means of a standard alkali solution.

Ammonia at high temperatures is decomposed, although the decomposition proceeds slowly when the ammoniacal gas is mixed with other gases. Lunge quotes the researches of Ramsay and Young on this question, as reported in the *Journal of the Chemical Society*, 1884, vol. xlv., p. 88. They found as follows:—

THE PERCENTAGES OF AMMONIA DECOMPOSED BY HEAT UNDER VARYING CONDITIONS OF TEMPERATURE, ETC.

(1) With a porcelain tube filled with broken pieces of porcelain:—

At 500° C.,	1·575	per cent.	decomposed.
„ 520° C.,	2·53	„	„
„ 600° C.,	18·28	„	„
„ 620° C.,	25·58	„	„
„ 680° C.,	35·01	„	„
„ 690° C.,	47·71	„	„
„ 810°-830° C.,	69·50	„	„

* "Bericht über die Wiener Austellung," i., p. 194, Hoffman, quoted by Lunge.

The material of the vessel used in determining these decompositions has a decided influence on the results, as shown in the next table :—

(2) With an iron tube filled with broken pieces of porcelain :—

At 507°-527° C.,	4·15	per cent decomposed.
„ 600° C. (current very fast),	21·36	„ „
„ 600° C. (current much slower),	34·44	„ „
„ 628° C.,	65·43	„ „
„ 676°-695° C.,	66·57	„ „
„ 730° C.,	93·38	„ „
„ 780° C.,	100·00	„ „

(3) With a plain glass combustion tube lying in an iron tube :—

At 780° C., ... 0·24 per cent. decomposed.

(4) With a glass combustion tube filled with fragments of broken glass tubing :—

At 780° C., ... 1·72 per cent. decomposed.

(5) With a glass tube filled with strips of ignited asbestos cardboard :—

At 520° C.,	2·90	per cent. decomposed.
„ 780° C.,	100·00	„ „

(6) With a plain iron tube, no oxide of iron present :—

At 780° C., ... 100 per cent. decomposed.

(7) With an iron tube partially oxidised, and therefore water formed :—

At 780° C., ... 95 per cent. decomposed.

(8) With a glass tube containing several lengths of an iron wire :—

At 760° C., ... 75 per cent. decomposed.

(9) With a glass tube containing several lengths of copper wire :—

At 760° C., ... 2·0 per cent. decomposed.

(10) With a glass tube filled with copper reduced from the oxide to give a large surface :—

At 780° C., ... 50·2 per cent. decomposed.

" The results may be summed up as follows :—(1) Under the most favourable circumstances (with an iron or porcelain tube, or a glass tube containing asbestos) the temperature at which ammonia gas begins to decompose lies a little below 500°. (2) In contact with a glass surface, the temperature at which decomposition begins is much higher. (3) The influence of the time of exposure is very great. (4) The nature of the surface of the containing vessel exerts an enormous influence on the amount of decomposition. (5) The amount of decomposition is greater when the area of surface is increased. The decomposition was never absolutely complete, just as Deville had found when decomposing ammonia by the electric spark, probably because N_2 and H_2 re-combine to a slight extent."

In contact with incandescent carbon ammonia is resolved into ammonium cyanide and hydrogen, $2NH_3 + C \rightarrow NH_4.CN + H_2$.

In the manufacture of sulphate of ammonia the sulphuric acid used has also an influence on the resulting sulphate ; that made from brimstone is the best, whereas acid manufactured from pyrites often contains considerable quantities of iron and arsenic, both of which colour the ammonium sulphate ; in order to avoid this discoloration, and to remove any arsenic from the saturater, several methods have been devised. Meadows proposes, in B.P. 5520, A.D. 1884, to add a certain quantity of tar, pitch, oil, or the like for the purpose of " melting " these agents in the saturater and forming a scum containing the iron and arsenic that rises to the surface of the liquid and is removed. Another process noticed by G. Lunge, and which he states had been worked very successfully in Holland, used ordinary pyrites acid to which was added a quantity of " *vitriol-tar*," that is, sulphuric acid after having been used in making crude benzol, containing a large amount of tarry matter. On the acid being saturated with the ammonia the tarry matters are precipitated and rise to the

surface, carrying with them all the iron and arsenious sulphide; the scum is removed, and the resultant ammonium salt obtained perfectly white. The gases emanating from the ammonia and benzol plant are generally made use of by being brought back to the ovens for the purpose of heating them, or are consumed in the flues, so that no nuisance is created by gases from the ammonia process escaping into the atmosphere, as was formerly the case; carbon dioxide, sulphuretted hydrogen, and a small amount of hydrocyanic acid used to escape, together with a large amount of steam. These gases, chiefly from the working up of ammonia liquor, were a nuisance to the neighbourhood of the ammonia works unless they were effectually disposed of, such as by leading them (after proper cooling and condensation of the water) under the fire grates, so that they might pass through the incandescent carbon in the fire, and thus become changed, and ultimately pass away with the furnace gases into the chimney.

Benzol.

Within the last few years the demand for benzol and its homologues, toluol, xylol, and solvent naphtha, has increased very rapidly; the internal combustion engine formerly using petrol spirit has opened up a new market for benzol spirit, whilst the demand for benzene, toluene, and naphtha in the manufacture of explosives and dyes, and as solvents for rubber, has now developed an enormous industry, whereby these matters, which were formerly neglected and wasted, are now extracted from the gas. The recovery of benzol as well as the other by-products from the carbonisation of coal has become a very profitable adjunct to the manufacture of metallurgical coke on the one hand, and lighting gas on the other. The process is carried on at the coke ovens where the by-products are recovered without any loss to the gas from which it is extracted; but with lighting gas this does not altogether apply, as the extraction of hydrocarbons reduces the thermal efficiency of the gas, and formerly would have been prohibitive when a certain candle power had to be maintained per cubic foot of gas; but with the incandescent mantle, where thermal units can be substituted by other means, it is now possible to extract the benzol as a commercial article from the gas, and to supply the deficiency with other gases that can be manufactured cheaply and which, for heating purposes, answer as well as the benzolised gas.

The importance of the benzol industry is growing every day, due to the fact that as the petrol deposits are depleted, recourse will no doubt be directed to benzol as a substitute.

The extraction of benzol from coke oven gas, when the gas is used for power purposes, only reduces its potential value by from 5 to 10 per cent., a consideration not worth comparing with the present and future possibilities of the benzol extraction. All classes of coal do not carry the same amount of benzol; the different coals from various countries, and also different seams in the same colliery, do not carry the same benzol content. The following list prepared by Messrs. Coppée shows the average amount of benzol recovered from various qualities of coal in this country :—

South Yorkshire,	2½ to 3 gallons of crude benzol per ton of coal.
Derbyshire,	,, ,, ,, ,, ,,
Staffordshire,	,, ,, ,, ,, ,,
Sunderland,	,, ,, ,, ,, ,,
Durham,	,, ,, ,, ,, ,,
Scotland,	,, ,, ,, ,, ,,
South Wales,	1 to 2 ,, ,, ,, ,,

The process of obtaining benzol, whether from the oil used to absorb the benzol from the gas, or from the distillation of tar, is the same, and is effected by means of steam, used as a convenient heat conductor to the benzol stills.

The first part of the process is the washing of the gas with creosote oil, which absorbs the benzol and all its homologues.

The second part of the process consists in submitting this benzol-saturated oil to distillation, yielding a product termed "crude benzol," of about 65 per cent. of benzol.

The third part of the process is the refining of this crude distillate for the production of 90 per cent. benzol, 50 per cent. benzol, and solvent naphtha, pure benzene, toluene, xylene, etc.

The final products from crude benzol without residues required by the trade are as follows, according to Lunge :—

DISTILLATE, PER CENT.

Temperature.	100° C.	120° C.	130° C.	160° C.	200° C.	Specific Gravity.
90 per cent. benzol, . .	90	..	..	..	..	0·885
50 per cent. benzol, . .	50	90	..	..	..	0·880
Solvent naphtha, . .	..	..	20	90	..	0·875
Heavy naphtha, . . .	..	..	..	..	90	0·880

The rectification by steam is either applied directly, that is, steam is blown into the liquid, or indirectly through the medium of pipes (dry steam); however, in the former case the steam will carry away substances that boil at a higher temperature than 100° C.; when applied to the oil, it is only applied to the last stage of the process, after the application of the dry steam. The stills are generally, however, adapted for either process, and contain an arrangement for dephlegmation or partial condensation of the water vapour.

The steam used for this purpose should have a pressure of at least 50 lbs. per square inch in the apparatus, and should be perfectly dry, preferably superheated; in ascertaining the pressure, the gauge on the boiler is not to be relied upon if the steam has to travel far in pipes, but it should retain its pressure heat in the apparatus, which should be there ascertained.

The apparatus used for the distillation of the crude oil for the production of benzol and its homologues varies considerably in details, although plants of modern construction pretty well resemble each other in all essentials, and fig. 216 shows in diagrammatic form a modern plant by Messrs. Coppée for the recovery and rectification of benzol. Fig. 215 is a similar plant by the Otto Co. Following the letters of reference on the diagram, fig. 216, A is the tank waggon charged with the oil, which is passed into the tank D; the gas from the coolers is brought by the main pipe to the series of scrubbers B, inside which are placed grids of wood for the purpose of spreading the oil in order to give as much surface contact as possible to the gas during the scrubbing operation which goes on inside the scrubbers. The oil is circulated through these scrubbers by means of pumps, C, C, C, situated somewhat below the scrubbers; the flow of the oil is in the opposite direction to that of the gas, so that the fresh oil acts upon the almost inert gas, and as it descends it encounters richer gas; by this means a perfect absorption of the benzol is secured. From these scrubbers the benzolised oil passes away to the storage tank D, whence it is pumped into the high level tank E; from this high level tank it flows by gravity to the dephlegmator through the heat exchangers F, from which it absorbs the heat

from the gaseous products leaving the still; after the water vapour has been extracted in the dephlegmator it passes to the superheater H, consisting of a number of steam coils enclosed in an outer casing; passing through this superheater and in contact with the heated coils the oil finds its way to the still; during its passage through the above superheater its temperature is raised to 130° C., at which temperature it overflows into the still J, where it is treated with live steam and the whole of the benzol is thereby driven off. The debenzolised oil flows away out of the bottom of the still into the heat exchanger F, where it gives up a large part of its heat to the rich oil passing in the opposition direction into the superheater; the poor oil now passes through the water-tube coolers K, and thence to the storage tank L, from which it is pumped up for use again in the scrubbers.

The benzol vapours, with the water vapour, ascend the still J, and are here partly fractionated by the "baffling effect." The lighter vapours together with water vapour leave the still and enter into the dephlegmating column at M, rising into the dephlegmator G. In this portion of the apparatus fractionation takes place, allowing the heat in the vapours to be transferred to the rich oil, by which means the vapours are cooled down considerably, and subsequently cooled in the water-cooled dephlegmator N, finally being passed through the condenser O. The benzol and water now enter a separator, where, by reason of their different specific gravities, the two liquids are separated; the crude benzol is led away to the measuring tank P, and then into the storage tank Q, fig. 216.

The oil passing from the dephlegmator G, which consists chiefly of naphthalene, is run into pans, where the naphthalene crystallises out, after which the oil freed from naphthalene is passed into the benzolised oil circulating tank, to be used in the benzol scrubbers. The process, as carried on in this apparatus up to this point, is a continuous one, and proceeds without interruption for any length of time, provided a little fresh scrubbing oil is added, when it is necessary.

The third part of the process for the production of commercial products is commenced by the purification and re-distillation of the crude benzol produced in the former process.

The crude benzol is delivered by means of compressed air into an agitator R, fig. 216, where the spirit undergoes a thorough washing with strong sulphuric acid of about 168° Twaddell (95·6 per cent. H_2SO_4), for the purpose of removing the foreign matters, such as pyridine, etc. By the action of the acid the foreign matter is collected at the bottom of the agitator, the oil being subsequently washed with water to remove the acid after settlement; it is then washed with a solution of sodium hydrate of about 20° Twad. for the purpose of neutralising any remaining traces of acid, and to remove the phenols; after allowing time for separation, the soda solution is run off and the spirit is again washed with water, after which it is run into the distilling tank, S, provided with both open and closed steam coils, and fitted with a rectifying column. It is here distilled in the first instance by means of the enclosed steam coil, the lighter vapours being given off; when this has been accomplished the open steam is admitted, which carries off all the higher boiling distillates. These vapours are carried up the column into the dephlegmator T, from which they pass to the condenser U, where they are condensed into the liquid state. The products of the above process are led into the preliminary receiving tanks V, and subsequently to their respective storage tanks W. The products are as follows:—

1. 90 per cent. benzol; *i.e.*, 90 per cent. of benzol distils over at 100° C.
2. 50 per cent. benzol; *i.e.*, 50 per cent. distils over at 100° C., and 90 per cent. at 120° C.
3. Solvent naphtha, of which 90 per cent. distils over at 160° C., consisting chiefly of xylene.

In the explanation of these fractionations, Lunge expresses the fractions as follows :—

1st. Up to 103° C. (by thermometer in still), yields 65 to 70 per cent. benzol.
2nd. 103°-110° C. yields 30 per cent. benzol.
3rd. 110°-130° C. yields nothing at 100° C., 60 per cent. at 120° C.
4th. Above 130° C. yields solvent naphtha.

He further states that in the second distillation the dephlegmator has the most of the work to do. By rectifying fraction No. 1 and keeping the temperature in the dephlegmator at 56° C., 90 per cent. benzol is obtained; while with the temperature in the dephlegmator at 80° C., 50 per cent. benzol comes over. It will be observed that as long as 90 per cent. benzol comes over the thermometer in the still will not exceed 100° C. When the temperature rises above 100° C. fraction No. 2 of the first distillation is run into the still; the temperature is now permitted to rise to 105° C., and the temperature in the dephlegmator to 80° C., the receiver being changed; 54 per cent. benzol is run over. The receiver being subsequently changed again, and live steam run into the still, solvent naphtha is now produced. It seems that attention to the temperature obtaining in the dephlegmator is more important to the successful manipulation of the distillation than the temperature of the still, and by so regulating the temperature of the dephlegmator the distillates coming over, when collected and mixed together, will produce a mixture spirit of about 50 per cent. benzol; but it must be remarked in the definition of certain percentages that this cannot be constantly depended on, and if certain fixed percentages are desired other means than the thermometer must be requisitioned, and tests made by more accurate methods, such as by the fractionating flask with a Liebig's condenser.

When the purer products are desired, the crude 65 per cent. benzol mentioned above is delivered into the still S, fig. 216, and here subjected to a re-distillation and condensation in quite a similar manner to that described above in the process for the formation of commercial products, the result being a crude benzol of better quality. The residue, consisting principally of naphthalene, is now run into the pan X_2, where the naphthalene is allowed to crystallise out. The crystals are transferred to a centrifugal dryer, and the oil that is here extracted is run back into the tank L and used over again in the scrubbers. The crude benzol thus obtained is put through a process of washing, then subjected to slow fractional distillation, and a finer dephlegmation. It is delivered by means of compressed air into the agitator R, where it is washed as described above for the commercial product; it is afterwards run into the still S_2. This still is a little differently constructed from the still S, having a taller column containing a larger number of trays for the purpose of obtaining a much finer separation. Distillation in this apparatus must be carried on very carefully and slowly; as it proceeds, the vapours pass up the fractionating column Y, then through the dephlegmators T_2, and after passing through the tubular condenser, U_2, are condensed into the liquid state. The pure products flow into the preliminary receiving tanks V_2, and thence to their respective storage tank W_2. By this process are obtained the following products :—

1st. Pure benzene, of which 90 per cent. distils over within a margin of 0·5° C.
2nd. Pure toluene, „ „ „ „ „ 0·5° C.
3rd. Pure xylene, „ „ „ „ „ 3·6° C.

As there is very little demand for this latter substance, the rectification is generally carried on for the production of benzene, toluene, and solvent naphtha.

The strong sulphuric acid used for washing the spirit, when it is no more capable of being used for this purpose, is run from the agitator into the acid-

Fig. 217.—"Coppée" Benzol Scrubbers at the Powell Duffryn Steam Coal Co., Ltd.

proof regenerator Z, fig. 216, and there it is heated by means of live steam. The matters which separate are removed, and the acid now cleansed is sent on to the ammonia plant for use in the saturater. The fumes that are evolved during this operation in cleansing the acid are received in the vessel Z_2, where

they are absorbed in water. Fig. 217 shows benzol scrubbers as erected by Messrs. Coppée at the Powell Duffryn Colliery, Bargoed, fig. 218 the coolers and naphthalene separators, and fig. 219 the pure benzol and toluol stills. The benzol plant of Messrs. Koppers and that of the Otto Coke Oven Company

Fig. 218.—"Coppée" Coolers and Naphthalene Separators at the Powell Duffryn Steam Coal Co., Ltd.

are almost identical with that of Messrs. Coppée already described; in fact, most of the coke oven construction companies build their plants upon similar lines; a few details in each respective system may differ, but, on the whole, the processes are similar, and a detailed description would practically amount to a repetition of the foregoing.

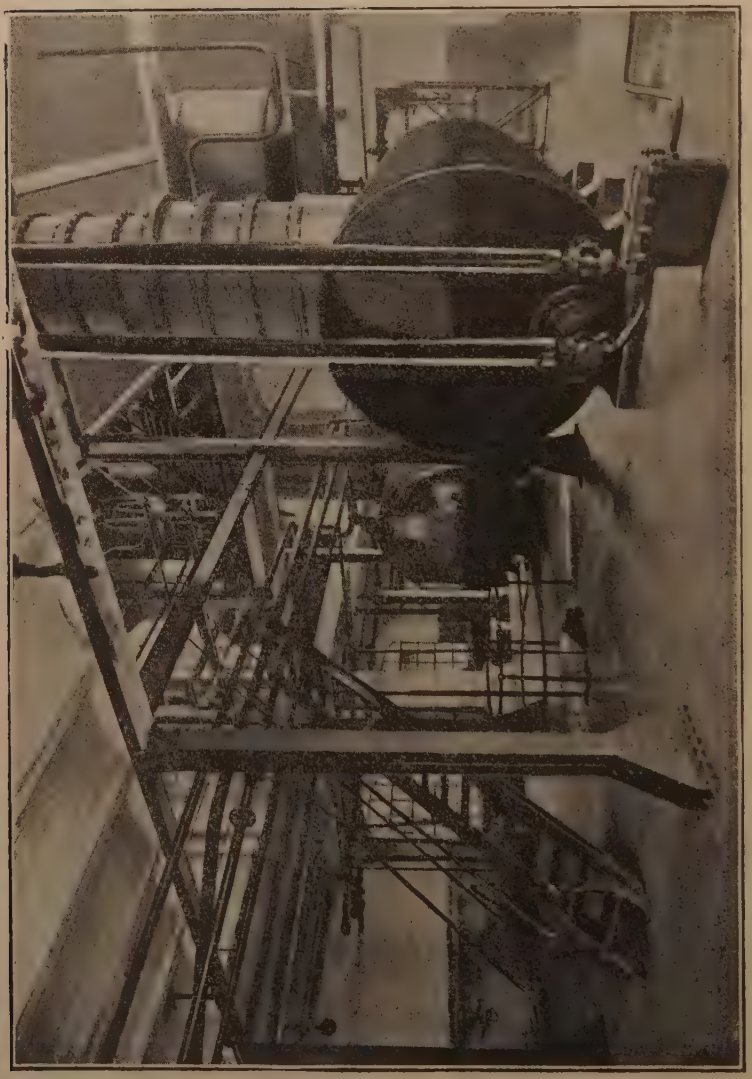


Fig. 219.—Pure Benzol and Toluol Stills at the Powell Duffryn Steam Coal Co., Ltd.

CHAPTER XII.

GAS MANUFACTURE.

It is now many centuries since illuminating gas was first made; probably the first intimation of this illuminant was the discovery of natural gas, issuing from the ground, and which had taken fire. There are a great many districts where gas is thus evolved from the ground. It is recorded that in the State of New York the existence of this gas was accidentally discovered while taking down a mill which was situated on the banks of the Canadaway River. A bore hole having been made down into the bituminous limestone from which the gas issued, the latter was used for illumination purposes in the locality. The gas was examined by Fougue, who found it consisted of marsh gas (CH_4) and ethane (C_2H_6). Subsequently several districts in the United States were found to possess this natural gas, which was collected and distributed for illumination purposes.

In the salt mines in Hungary similar gas was discovered and was used for illuminating the workings in the mine; it was ascertained that the gas issued from beds of marly clay which were interstratified with the beds of rock salt. In several other localities discoveries of natural gas were made; in the Province of Schechuan, in China, in the salt mines, the gas is collected and conveyed to where it is used in bamboo cane tubes. In Central Asia in the locality of the Caspian Sea, in Bengal in India, and in several other localities in different parts of the world, natural gas has been used for a very long time. This gas, no doubt, emanates from the coal measures, or oil shales; in process of time, exposed to pressure and an elevation of temperature, the hydrocarbons of these measures have been distilled and deposited in localities where they have been preserved in the form of oil or gas; in the case of the former, in some absorbent strata, and in the latter, in subterranean caves, where, not finding a ready outlet, it is often pent up under considerable pressure. This being the case, the sinking of a bore hole into the region holding this gas, as in the instance cited above on the banks of the river in New York, or in the salt mines, results in the gas finding a means of escape.

Illuminating gas is, therefore, as old as the creation of organic matter, whether vegetable or animal; there is no doubt but that it emanates from either, or both of these; under the chemical laws of nature all organic substances undergoing change produce gases. These gases, pent up underground, often found an escape from some crack or fissure in the ground, and sometimes became ignited; they were regarded by the ancient natives as coming from the "abodes of their Gods." In the oil regions of Baku these gases have long been known as the "holy fires of Baku."

The application of the destructive distillation of coal, or wood, is of modern times, yet as far back as 1695 Thomas Shirley is said to have traced to the coal measures the gas that issued from the "burning well" of Wigan, in Lancashire; and as early as 1664 Clayton declared that in the dry distillation of coal by heat a combustible illuminating gas was produced, and could be collected and used. In 1787 Lord Dundonald obtained a patent for the production of tar by the destructive distillation of coal, at Culross Abbey. The tar was conducted by

pipes into cylinders of brickwork, which had openings for the escape of the "uncondensable part of the products"—viz., the gas. It is stated that the workmen attached a pipe of cast iron to the opening, and applying a light at the end, the gas flamed and gave them the light to execute their work. It is also stated that Lord Dundonald burned this gas in the Abbey as a curiosity, and for this purpose a vessel was constructed to hold the gas, which was frequently filled and carried up to the Abbey, where the gas was burned to illuminate the hall.

The practical application of coal gas for illuminating purposes was, however, discovered later by a Scotchman named Murdock, who in 1792, while employed at Redruth in Cornwall, carried out some experiments for the purpose of ascertaining the quantity and quality of the gases evolved in the dry distillation of coal, together with several other mineral and vegetable substances. He carried on these experiments for several years until in 1798 he removed from Cornwall to the vicinity of Birmingham, to the works of Messrs. Boulton & Watt at Soho; here he constructed and fitted up a plant for manufacturing coal gas, and by means of pipes distributed it to various parts of the premises for illumination; subsequently this plant was enlarged, and the gas manufactured was conveyed to the adjoining works, and in this manner was commenced the commercial manufacture and distribution of coal gas. Mr. Clegg, who succeeded Murdock at Messrs. Boulton & Watt's, made several improvements in the manufacture of the gas. In 1810, F. A. Winsor took a great interest in this new illuminant, and for its manufacture and distribution obtained an Act of Parliament for the formation of a company, which became the Gas Light and Coke Company. The first public application of this new means of lighting was the street lighting in 1813 on Westminster Bridge, and in the year following most of the streets in Westminster were illuminated with gas. Gas lighting became so popular that all the principal towns in the kingdom were using it within a few years of its first introduction, at first principally in shops and public places. The gas lighting of domestic apartments came more slowly, no doubt due to the apprehension of danger from explosion, arising in many instances from imperfect workmanship in fitting up the service pipes, which state of affairs in the infancy of gas lighting was to a large extent inevitable; but experience in the use of gas gradually gave rise to confidence, and the superiority of the illumination as compared with candles was proved, so that domestic gas lighting gradually became more universal. At first the illumination was poor, owing to the method employed in burning the gas; this was subsequently improved by the new burners employed, causing the gas to be more thoroughly consumed, and to develop a hotter and broader flame. The manufacture of the gas and its purification were also gradually improved, and with the introduction of more perfect apparatus for distillation of the coal the gas industry became firmly established.

Retorts.—In order to manufacture lighting gas the distillation process has to be conducted out of contact with air, in closed retorts; the coal, or other organic substance producing gas, has to be heated in vessels which are air tight; simple as this seems to the ordinary individual, the process of successfully accomplishing the distillation at the proper temperature, to produce the requisite results, is by no means a simple one; many difficulties occur, but these have been to a large extent mastered by perseverance in practical experiment and by the adoption of improvements made through experience gained in the manipulation of the apparatus employed to carry on the process.

In order to enclose a body of coal for distillation, apparatus is required part of which consists of retorts in which the coal can be conveniently charged

and heated, and at the conclusion of the operation the coke easily withdrawn. Retorts for this purpose were first made of cast iron, of a circular section, and were generally from 6 to 7 feet in length, and about 12 inches in internal diameter. The difficulty of heating these retorts soon became apparent; the temperature required to procure the desired yield of gas from a given quantity of coal was higher than the cast iron could stand, consequently the underside of the retort, exposed to the action of the fire, soon wore out, before the heat had had any detrimental effect on the upper side; therefore, at the suggestion of Prechtl, the original circular section was changed for an elliptical one, which was further improved by working the lower side convex inwards. The length

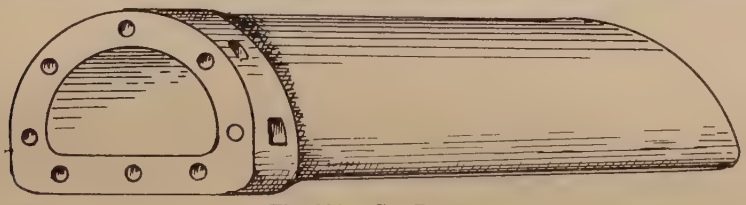


Fig. 220.—Gas Retort.

of the retort exposed to the fire was about 6 feet 5 inches, exclusive of the mouthpiece, which was always made separately from the retort itself and was joined on to it by means of a flange, with bolts and nuts. In order to preserve the retorts from the intensity of the heat of the furnace, which was placed immediately underneath them, they had a brick arch placed over the fire; and to allow for a more perfect heating of the retorts with this arrangement, a series of flues was constructed that conducted the products of combustion from the fire grate along the bottom of the retort, then along the sides to the chimney. The great drawback to this system was the lowness of the carbonising temperature, and this prevailed until the advent of the fireclay retort; these new

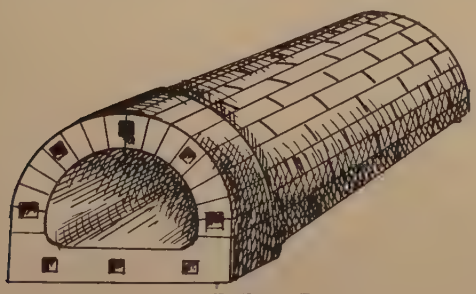


Fig. 221.—Built-up Retort.

Fig. 222.—Mouthpiece End of Built-up Retort.

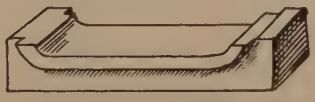


Fig. 223.—Sole Piece for Built-up Retort.

retorts were not only placed in the direct line of the fire, but they could be urged to very much higher temperatures without doing any damage.

Various shapes of clay retorts were made; at first they were formed of circular section, like those of cast iron, which they superseded, then of oval section, and laterally and finally of a D section, as shown in fig. 220. Each retort is furnished with a mouthpiece, fitted with a gas-tight door, the neck of which is cast to a flange or socket pipe, carrying the ascension pipe. The door is arranged with a lever attachment, by which it can be very firmly closed. The mouthpiece is fixed to the clay retorts with bolts and nuts fitted into the flange of the retort, as shown in figs. 220 and 221. Difficulty was experienced

in carbonising coal in the clay retorts, owing to their cracking, and allowing the gas to escape ; at first they were taken out and replaced, but this was to no purpose, as those subsequently installed also cracked ; by continuous use it was soon made apparent that the cracks became filled up with carbon, deposited from the escaping gas, so that in a few days the retorts were perfectly gas-tight, although very much cracked. This state of affairs obtains at the present

Fig. 224.—Front View of " Glenboig " Retorts at Glasgow Gas Works.

time with clay retorts, and although the retorts may crack up into several pieces, owing to the cementing influence of the deposited carbon these retorts become quite sound and gas-tight. Figs. 224 and 225 show a setting of several retorts at the Glasgow Corporation Gas Works, made by the Glenboig Fireclay Co., and which had been in constant use for 2,380 days.

Retorts have been constructed of brick, but this is rather difficult to accomplish successfully, unless the bricks are very well shaped and the joints level; a certain kind of silica-sand brick has been used, along with other special bricks in this method of building retorts, with more or less success; with regard to

Fig. 225.—Back View of "Glenboig" Retorts at Glasgow Gas Works.

the former, these bricks are capable of being "gauged," that is, rubbed or cut down to a gauge, so that they fit perfectly one against the other, with a fine joint; the author has seen these retorts used in a gas works with great success. When they are fired and the charge inserted, the gas at first

finds its way through the joints in the brickwork, but subsequently the deposited carbon soon fills up all the leaks, and the retort becomes perfectly gas-tight; fig. 221 shows one of these retorts.

The art of the furnace builder in the construction of these retorts is exhibited in the skill with which the joints are made; it is a very simple matter to plaster the bricks with copious layers of fireclay, in order to build up a construction like a retort, but when such a construction is heated the water in the fireclay cement contracts and leaves the joints open; the retort is thus distorted, and due to the bricks falling away from the thick joints a very weak and unsatisfactory retort results. On the other hand, when the furnace builder has the proper skill in fixing gauged brickwork, making as thin a joint as is made with putty, with a very thin film of fireclay, with each brick bedded and firmly fixed in its proper place, such a retort is of the first order when it has been evenly

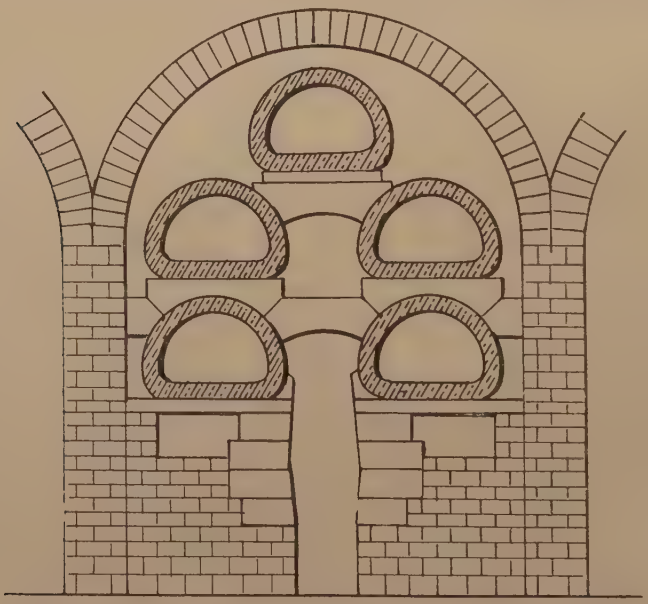


Fig. 226.—Retort Setting for Five Retorts.

fired, and the fireclay cement has been hardened; a retort is produced in every way as good as, if not superior in shape and durability, to retorts made in one piece. When retorts are thus constructed with well-burned bricks, and the shrinkage in them has been developed to its maximum extent in the kiln, they ought to be superior to those made in one piece, because they will not loose their shape and cannot crack by reason of contraction.

With regard to successful carbonisation, it may be questionable whether retorts built up with bricks are so good as those made in one or more lengths of fireclay tube, on account of the necessarily greater thickness of the built-up retort; the heat cannot penetrate into the interior so well as with the thinner tube retorts; carbonisation will be more rapid in the latter, and higher internal temperatures can be more steadily maintained, which is a consideration in the manufacture of gas; nevertheless, built-up retorts made with firebrick from

the Glenboig Company have, according to Hislop, given entire satisfaction. Fig. 221 shows the shape of these retorts built up with firebricks. The bricks are specially made to a radius to form the top and sides, the bottom being formed with slabs, as shown in figs. 222 and 223. The mouthpiece end or sole

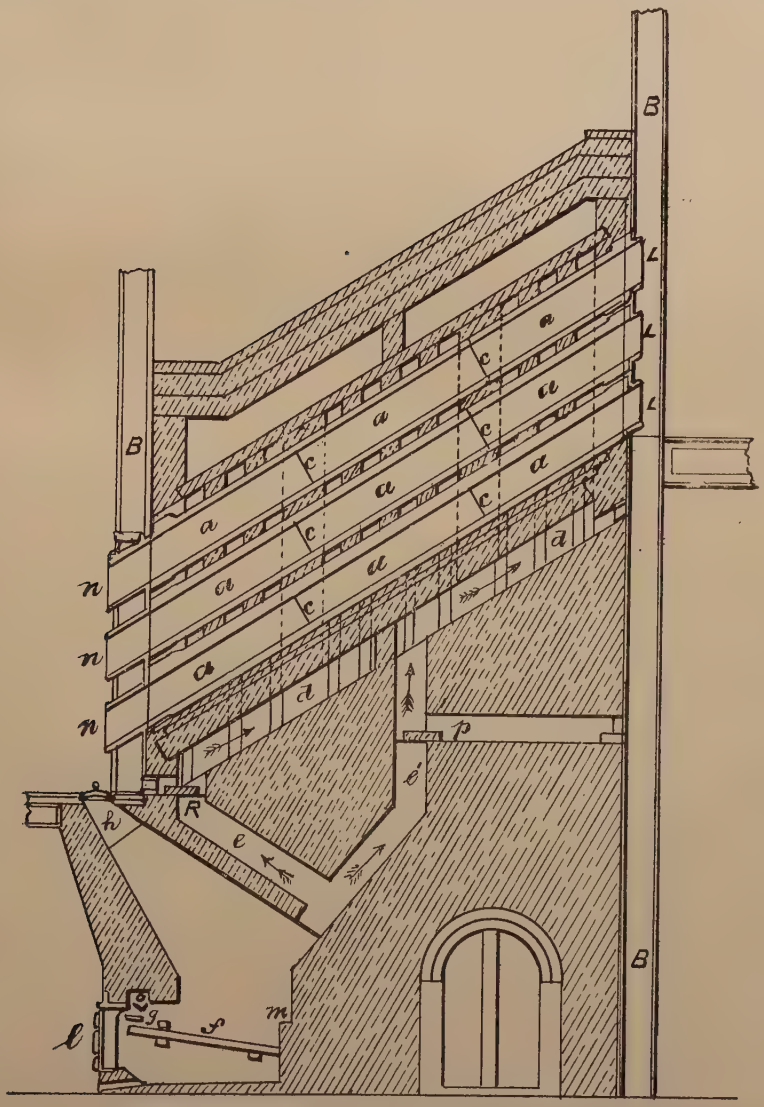


Fig. 227.—Longitudinal Section of Bench of Inclined Retorts and Gas Producer.

is shown in fig. 222, with bolt holes formed in it to fix on the cast iron mouthpiece.

Retorts are built into "settings," generally having five or more retorts; fig. 226 shows a section through a setting of five retorts; the fireplace is in the

centre, two sets of retorts are on either side over each other, and one is on the top in the centre; these settings are formed into a bench of several such settings placed alongside each other; the retorts are generally about 21 inches wide by 15 inches high inside, and the setting is 6 feet 6 inches in width inside the walls. The setting shown in fig. 226 has main walls on each side, supporting the arch above, which form the permanent construction of the furnace building; the retorts set into this building are separate, and not connected to the permanent walls or the arch, so that the whole structure with the retorts constructed inside these permanent walls and arch can be entirely removed for replacement.

A longitudinal section through a bench of retorts is shown in fig. 227. This is a similar construction to that above described; the arch, however, is flatter, but the walls are similar; the retorts and their settings are all constructed independently of the main walls.

The settings are determined by the size of the retorts that have to be accommodated, and where these are large, as in through retorts, they are generally constructed in two or three lengths, and jointed together; these can be set either horizontally or inclined, or vertical; the latter have come into use only recently, and will be subsequently described. Retorts were originally set horizontally, but when long through retorts came into use—that is, retorts open at each end, as distinguished from the earlier type with a closed end—they were found difficult to charge and discharge, and inclined retorts were then adopted. In small gas works, the retorts are usually in short lengths, and are closed at one end, whereas in large works with the through retorts there is a mouthpiece fitted to each end of the retort; these retorts are generally constructed 20 feet in length, made up in two or three sections. The retorts are generally made with an internal width of 20 inches, and a height of 13 inches, and formed of a Ω shape; the thickness of the material forming the retort is usually 3 inches. There are occasionally retorts constructed with an internal measurement of 22 inches by 16 inches. The end of the retort designed to carry the mouthpiece is made thicker than the rest of the retort, in the form of a collar, 4 inches thick and 9 inches wide around the end. This flange or collar is perforated for the purpose of receiving the bolts for fixing on the mouthpiece.

Mouthpieces.— The mouthpieces fixed on the end of the retorts are always made of cast iron, and the frame or flange is of the same size and design as the end of the retort; the flange cast on the mouthpiece has holes cast in it, corresponding with those on the end of the fireclay retort, to receive the fixing bolts; the latter are generally placed in the retort flange, and the screwed ends of the bolts are pushed through the holes in the mouthpiece flange, and secured with nuts and washers. A luting of fireclay mixed with iron turnings and moistened with water, and into which has been dissolved some chloride of ammonia, is placed on the mouthpiece to form a joint on the fireclay retort; the latter salt causes the iron turnings to oxidise, binding the fireclay to the retort and the iron mouthpiece. Fireclay alone would be useless in this position, because the temperature is not high enough to harden it permanently, and by reason of its desiccation it would shrink and fall away, leaving a space between the iron and retort. Fig. 228 shows a form of mouthpiece designed by Messrs. Holmes, of Huddersfield, fitted with a self-sealing gas-tight lid. The top of the neck of the mouthpiece is fitted with a socket, cast on to secure the gas ascension pipe. The lid or door is, together with the frame, machined, so as to form a very accurate and even joint, whereby the same is made gas-tight. Fig. 229 shows the bench of retorts with the mouthpieces and the ascension pipes fixed

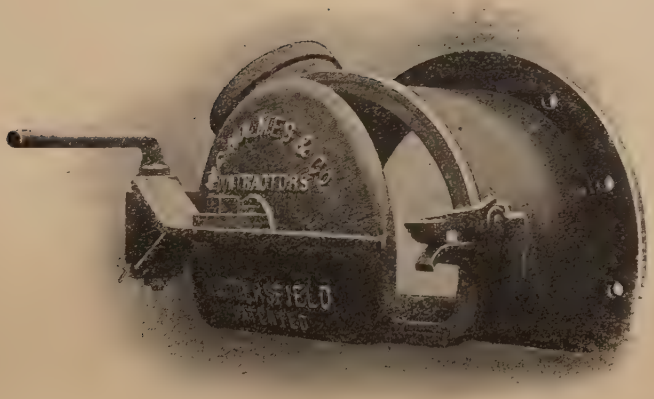


Fig. 228.—" Holmes " Mouthpiece with Self-Sealing Gas-tight Lid.

to them at one end, and with the dip pipe into the horizontal main at the other end of the ascension pipes.

Fig. 229.—Mouthpieces and Ascension Pipes to Retorts.

Settings.—The furnace construction for the purpose of containing and properly heating the retorts is termed a setting, the retorts being placed or set therein. Settings may contain from three retorts upwards; they are built with firebrick on the internal parts, the outside being formed of ordinary brick; the settings consist generally of division walls, between which the retorts are set, and over which are constructed arches, constituting the permanent part of the setting. The construction of the fireplace, and the beds for the retorts, the flues and other details, are all inside the permanent walls, and are not attached to them. Settings may contain as few as three retorts, or as many as twelve retorts, served by one fireplace; they may be horizontal or inclined. (Vertical retorts are described later, as they form a class by themselves.) The horizontal and inclined retorts are set upon supporting walls, usually placed about 2 feet apart, throughout their entire length, and the number of these supporting walls varies with the length of the retorts.

Furnaces for heating these settings also vary, there being several different designs of furnaces in use. The simplest form is that in small works, where the retorts have only one end for charging or discharging; they generally have dead ends, which are often made separately from the retorts—that is, the retort is formed in one piece and the end in a separate piece, and is fixed on with fireclay when built into its place. The fireplace forms the central part of the setting, the retorts being arranged on either side and above it; should there be five retorts in a setting, these will be arranged as shown in fig. 226. The furnace is generally fed with hot coke from the retorts as they are drawn; settings with fire grates using direct firing as formerly employed, are now practically discarded, except in small experimental settings. Modern settings are generally designed on the recuperative or regenerative principle.

Gas-Fired Regenerative Furnace Settings.—In the construction of furnaces, great care has to be taken with regard to the selection of a site; in the case of gas manufacture this is not always easy.

Gas works for the supply of towns are generally situated on the lowest level possible, so that the gas may rise in the mains by gravitation; with this in view, the choice of a site requisite for the purpose may result in a damp situation, and special care will be required to ensure that the foundations are perfectly dry; this is most essential for all classes of furnaces, and in particular for settings for gas retorts.

A firm and substantial foundation should be secured, and if the subsoil is of a soft or clayey nature it should be excavated to a considerable depth, so that the heat of the settings shall not dry up or shrink the clay, or similar subsoil, thereby disturbing the walls and other constructions.

Concrete composed of clean gravel and Portland cement is the best that can be used in such situations. It is not necessary to excavate over the whole of the site occupied by the furnace house, but, if the ground requires it, a system of dwarf foundation walls may be built at a few feet apart upon concrete, and upon these walls arches can be formed, and upon these arches the superstructure can then be constructed. A course of cement concrete over the arches a few inches in thickness will be a protection from damp rising up the walls, and should, if confined to the retort settings, extend to 12 or 18 inches beyond the walls. If there is to be a chimney shaft constructed on this site, the foundation for it will have to be made much deeper, on account of the pressure on the base by reason of the height and weight of the chimney.

The outside walls of the settings will have to be supported by buckstays; the lower ends of these may be placed in holes at the requisite distance apart,

formed in the concrete foundations, and if necessary bound with tie rods, placed on the foundations, but generally the latter are not necessary in good concrete. In building the settings care should be taken to see that the work is carried out in the manner of furnace building, as distinguished from ordinary house building. The manner of construction and laying the bricks is important; they should be laid with their joints, if in mortar, well hammered down and every course flushed up with mortar; the same applies to firebrick set in fireclay; thin joints of fireclay, with the bricks well hammered home, produce the best and soundest work. The main walls having been finished up to the arch springing, the arches should be constructed upon properly formed skew-backs, and upon wood centres, turned to the exact radius; the skew-backs or springings should be laid to the proper radius line of the arch; the arches should then be laid with firebricks on the wood centres, the bricks being placed endwise and laid perfectly dry, care being taken to select bricks with good, even faces; the arch bricks are used to turn the arch to the true radius; a ring of this brickwork will thus be 9 inches thick; when the bricks have been all laid from the springings at each side, and finished up to the centre, the key bricks forming the central portion of the crown of the arch should be placed in position; bricks a little tight to fit in the space left should be selected, and these forming a line along the crown of the arch should now be hammered home with some force, if the arch is a wide one, so that the bricks forming the arch may rise a little from the wood centre, when the key bricks are driven home, which is generally performed by means of a hammer and a block of wood. Before, however, the required bricks are driven into the crown of the arch, attention to the buckstays is necessary, and these should now be placed against the walls, standing in the holes prepared for their bottom ends in the concrete; the tie rods are now fitted across the setting from the buckstays on one side to those on the opposite side, and tightened up to where they are to remain, after which the operation of driving home the key bricks can be performed. Buckstays are of various shapes and patterns; old permanent-way rails are often used for this purpose, and two of these placed alongside each other with a distance piece between them make excellent and stiff buckstays. The tie rod is then passed through between the two rails and through a washer plate on the outside of which is a nut, which can be screwed up to the requisite tightness. Tie rods are also sometimes made in two lengths with a right- and left-hand thread in their centre, with a long nut which, when turned round, tightens both ends of the tie rod at the same time.

When the first ring of the arch is thus completed, it will now require to be grouted with a grout of clay made into a paste, or into the consistency of cream; this fireclay grout must be well mixed and free from lumps, and run in all over the surface of the arch, the clay finding its way down into the interstices between the bricks when this is skilfully performed with a hard brush. A second ring of brickwork should be placed over that just finished, in the same manner, but if economy is necessary common building bricks with lime mortar as grout may be used, as there is no great heat to withstand on the outside ring of the arch. The arch will then be 18 inches thick.

The arch constructed over the retorts should be designed to facilitate an even distribution of the heat to the several retorts, so as to give the least amount of vacant space that will absorb heat, while at the same time to act as the conductor of the draught, avoiding any short-circuiting. In constructing settings for gas regenerative firing, several arches will have to be constructed inside the main arch; thus there will be required an arch over the

producer, one over the combustion chamber, and over the flues, and in various other parts of the settings. Arches are often turned over various parts for bearing purposes, or for conducting the heating and exit gases through the settings. In the construction of arches in the settings the greatest care should be exercised in selecting the best well-burned firebricks, and to set them firmly with their fireclay joints to prevent dislocation during the working.

Gas Producer.—The gas producer in modern settings is built in several ways as regards internal shape; some are formed without any arch top, others are formed with expanding sides, with round or elliptical arches, the exigencies of the

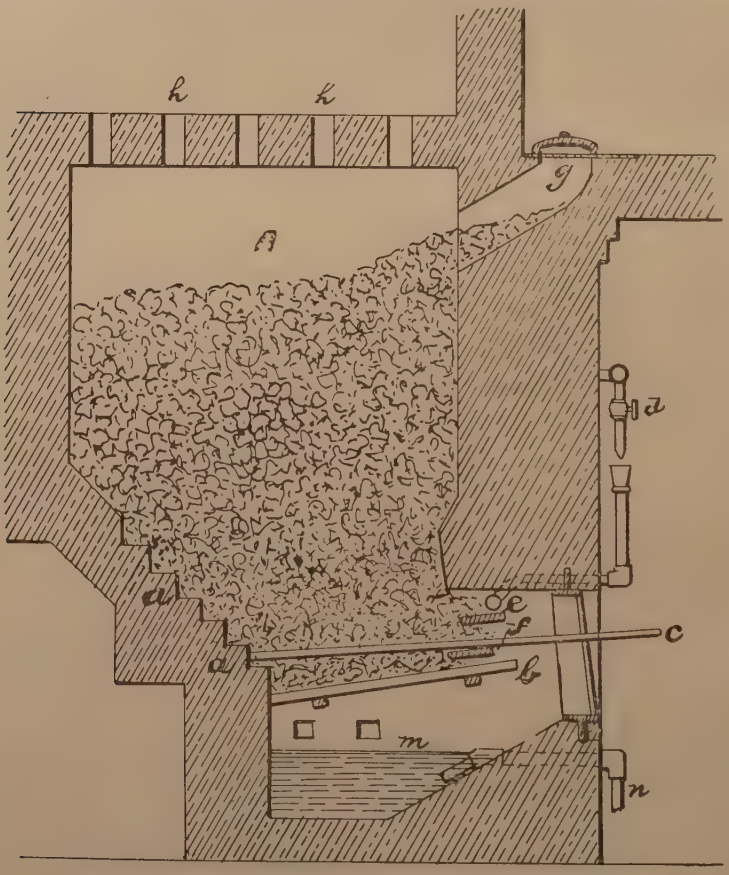


Fig. 230.—Section through Gas Producer for Gas Retort Bench.

site often determining the shape of the gas producer or generator; but, under ordinary circumstances, arches are generally turned over the top of the generator or producer. The side walls of the producer are generally tapered inwards towards the bottom of the firebars, for the purpose of contracting the grate area, and for checking the draught of primary air, which otherwise would rush up the face of the wall, instead of into the body of the fuel. The brickwork at the back of the fireplace is generally stepped back for this purpose, as shown at *a*, *a* in the vertical section through the producer in fig. 230.

When gas firing was first applied to the carbonisation of coal, in gas making, the gas producer was a separate apparatus; the gas produced was conducted to the furnace through large pipes, at a low temperature; but improvements subsequently made dispensed with the separate producer, and the latter became a part of the setting; this was at first fed with cold fuel, but by a further improvement the hot fuel from the retort was introduced into the producer, thus securing the initial heat of the incandescent fuel, while having the producer in the setting immediately beneath where the gas is consumed; the initial heat of the gas is likewise saved, and ignition by means of air heated also in the settings ensures more perfect combustion, with a resultant saving of fuel.

When cold fuel was used in the producer, a double producer was sometimes installed for the purpose of a continuous supply of hot gas to the combustion chamber, thus preventing the fluctuation of the heating when a fresh charge of cold fuel was placed into the producer.

Fig. 231 shows a general vertical section through a bed of horizontal retorts,

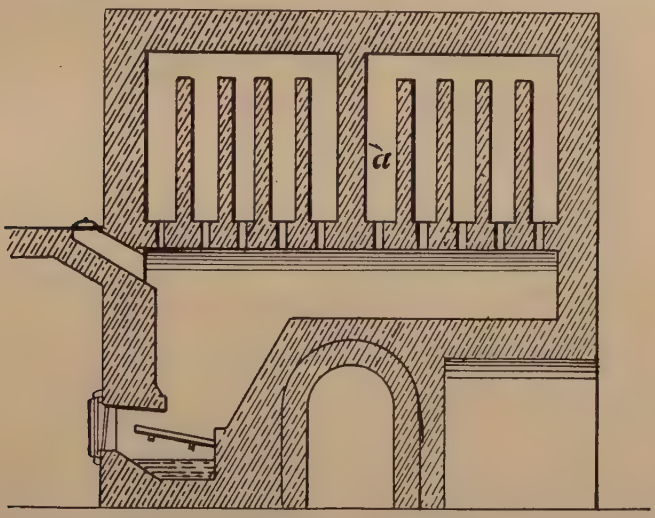


Fig. 231.—Longitudinal Section through Horizontal Bench Heating Flues.

with the producer, showing a central division wall between the two sides at *a*, for the purpose of more efficiently distributing the heat to the retorts; when a through bench of retorts is built this construction is generally adopted when the retorts are over 14 feet long.

Fig. 230 shows a detail section through the producer, as used in retort settings generally. A is the producer, which is fed with hot coke drawn from the retorts by means of the shoot *g*, and is covered on top with a lid. The producer is formed with a stepped back, as at *a*, *a*, to prevent a current of air rushing up the face of the wall. The fuel rests on the wrought-iron furnace bars *b*, *b*, which may be pulled out altogether for the purpose of clinkering. When this is performed, a series of clinkering rods, *c*, are pushed into the lower part of the fuel, as shown just above the lower drip plate *f*, and with one end resting on a ledge of the brickwork at the back wall; this supports the fuel when the bars are drawn out, and the clinkers dropped; the firebars are then inserted, and the clinkering bars withdrawn; the fuel then drops again on to the firebars.

The ashpit is formed with a water trough at *m*, and is provided with an air-tight door in front; drip plates are inserted at *f*, and a stream of water is caused to drip on to them from the pipe *e*, which is connected to a sight-feed, regulated by a cock on the pipe at *d*. Steam is also admitted to the ashpit along with the primary air; these are also under control by means of cocks and valves. The gas from the producer finds its way to the combustion chamber by means of the nostril holes *h*, *h*, which in a through setting are extended beyond the point shown in the illustration in fig. 232 at S and S′. Fig. 233 is a part section across the retorts and the recuperator flues beneath.

Inclined Retorts.—When inclined retorts were first introduced a problem presented itself in the equal distribution of the heating gas throughout the

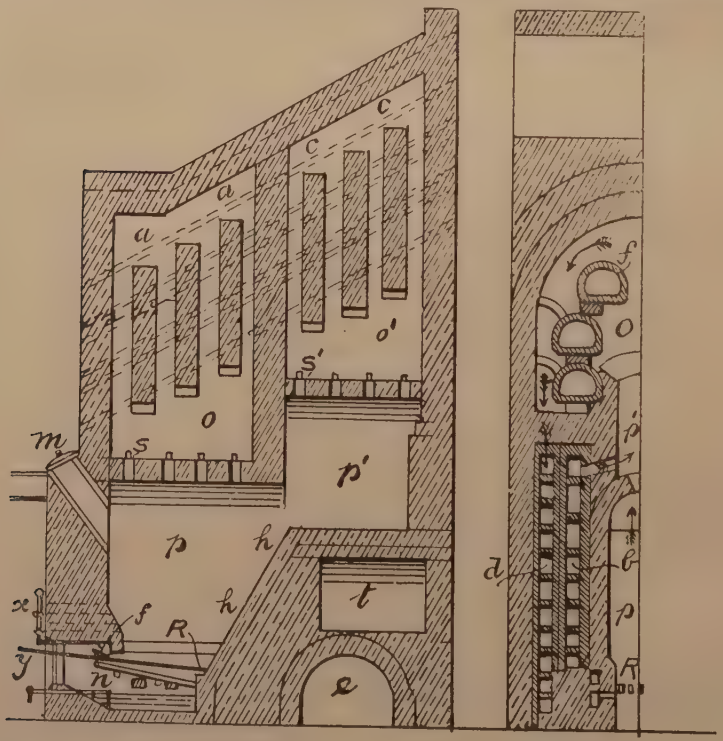


Fig. 232. Fig. 233.

Fig. 232.—Section through Gas Producer and Combustion Chambers. (Inclined Retorts.)
Fig. 233.—Section through Recuperators. (Inclined Retorts.)

setting; in order to procure an equable temperature in the retorts, the inclined base naturally allowed the gas to ascend to the higher level, and the gas and air was drawn away in an irregular and unequal manner; as the arch over the generator was at first formed to follow the inclined line of the retorts, the result was as indicated above, the heated gas rose to the highest point, while in the lower part there was a deficiency; fig. 234 shows an attempt to remedy this, but it was only remedied by constructing the arch over the producer horizontal, as shown in figs. 232 and 233, with a division wall separating the front from the back portion; the gas for feeding the upper part of the setting

is carried through an opening marked *s'* at the back of the producer into the gas chamber *o'*. The general construction of the gas producer, or generator, for either horizontal or inclined retorts, is in principle the same, except for

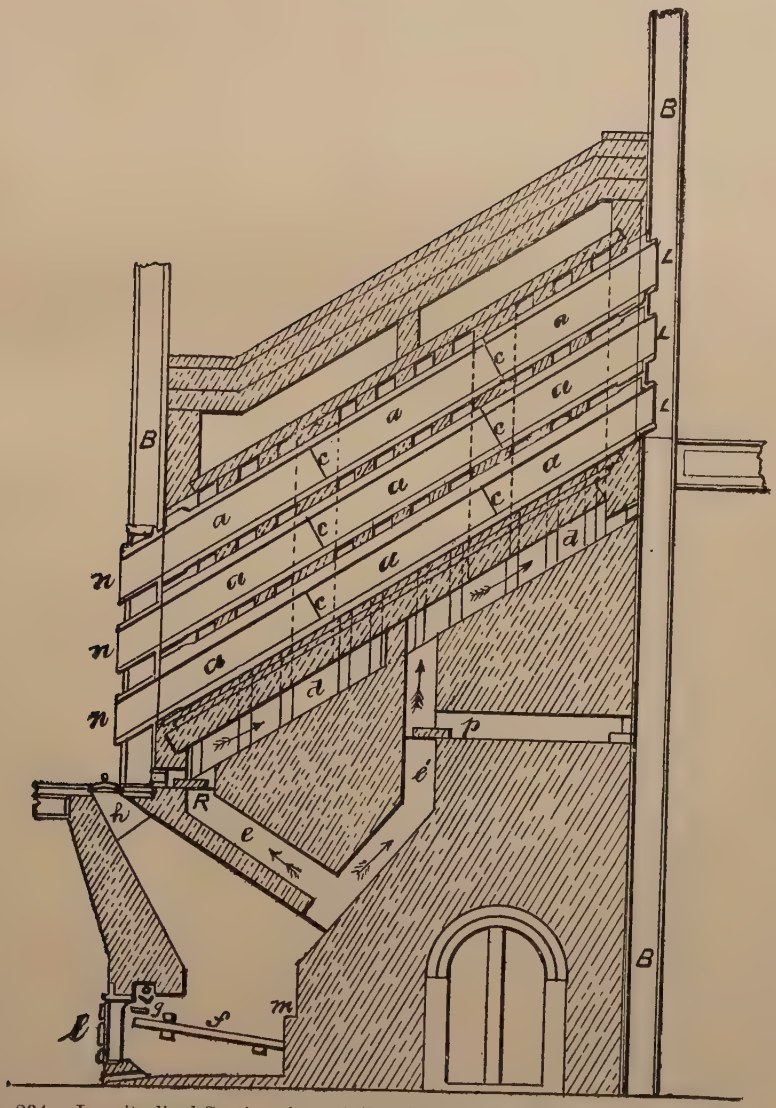


Fig. 234.—Longitudinal Section through Bench of Inclined Retorts and Gas Producer.

the difference above referred to in the construction of the roof for the equal distribution of the gas.

The gas generator is constructed as described already, and placed under the settings, as shown in fig. 234; it is often placed behind, in an inclined bed of

retorts, and consists generally of a furnace 2 to 3 feet wide, 8 to 10 feet deep, and from 4 to 5 feet in length from back to front internally, with steel firebars; these are sometimes formed hollow, with perforations for allowing steam to be introduced under the grate area. The water in the ashpit is quickly evaporated, and by the steam introduced the clinkers are kept soft, and the temperature on the bars is kept low. The steam rising up into the incandescent fuel, produces carbon monoxide gas and hydrogen, formed by the well-known reaction, $H_2O + C = H_2 + CO$. These gases, when again burned in the setting, will revert to water and carbonic acid, thus :—$H_2 + CO + O_2 = H_2O + CO_2$. The ashpit of the producer is enclosed by air-tight doors when the primary air is required to be heated; when this method is adopted, air valves are provided with means for regulation of the air supply upon the inlet on the outside walls; a flue is then built from the front wall round the ashpan, and terminating in two or three openings beneath the firebars, as at *m*, fig. 230, otherwise a damper is placed in front for the regulation of the primary air to the ashpit.

The charging door for the producer is generally placed on the upper floor, and covered with a lid; a fireclay tube is placed in the wall, through which is shot the hot coke from the retorts; an iron frame is usually built into the upper part, to receive the lid, and is made gas-tight.

Another improvement in the heating of the settings was the application of means for recovering the waste heat, which usually left the settings for the chimney. This has been accomplished in a very simple manner, by the construction on each side of the producer of recuperators, often called "regenerators." These consist of a series of flues, conducting the hot waste gases to the chimney, while the other flues, built alongside them, conduct the secondary air to the combustion chamber in the setting. These flues are built either perfectly perpendicular, or horizontal, or placed zig-zag between the walls of the producer and the main walls of the setting. Figs. 233 and 235 show the method of constructing these recuperators; fig. 233 shows the path of the exit gases descending through the flues, on the outside, and marked *d*, *d*, while the path of the secondary air is shown ascending through the flues on the inside, next to the producer, marked *b*, *b* in this illustration; this method is with horizontal heating flues, running from back to front along the walls of the producer; the flues being superimposed, one over the other, the exit of the waste gases is shown by the arrows descending into the exit flue to the chimney. The primary air, after recuperation, finds its way to the combustion chamber through the apertures marked S, S′, fig. 232. Figs. 232, 233, 234, and 235, which are respectively longitudinal and cross-sections, show the arrangement of these flues in a zig-zag manner. It will be observed, in the illustrations, that the secondary air makes its entry into the combustion chamber immediately in front of the openings in the arch of the producer, which admit gas to the combustion chamber. Thus, the air being heated as well as the gas, a very high temperature can be maintained in the retorts.

This part of the construction of the setting relative to the recuperation of the air is an important one, and should be executed with great care; the vertical system of flues is perhaps the best, and should be adopted in preference to the horizontal, on account of the joints in the flue pipes or blocks employed in their construction; in working, any shrinkage does not open the joints to the extent that would occur in horizontal flues. When cracks or leaks through defective joints do occur, the danger is in the transference of CO_2 into the secondary air flues, causing bad heats and bad combustion; on the other hand, the secondary air might be drawn towards the chimney, so that the combustion

chamber would be deficient in air, also causing bad heats, and a great waste of gas; this latter effect would probably more often happen than the former.

In constructing recuperators in settings it is advisable to divide them with partition walls, making four recuperators—that is, two on each side of the producer. By this means the stream of secondary air is broken up, and is more under control, by four dampers, than it would be otherwise; all the flue pipes and openings in the recuperators should be constructed with the same sectional area throughout, so that there is no undue pressure produced at any point. The combustion chamber is situated immediately above the producer, and the retorts are set with their supporting walls inside the setting, so that the secondary air and gas supply may expand round the retorts completely and find its way to the exit through the recuperator flues.

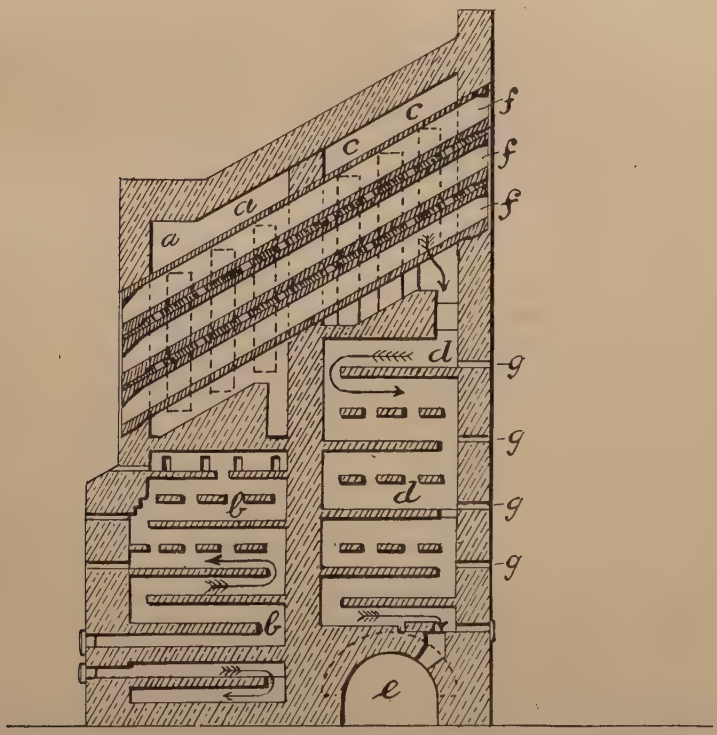


Fig. 235.—Longitudinal Section through Recuperators. (Inclined Retorts.)

Vertical Retorts.—The use of vertical retorts for the production of gas by the carbonisation of coal goes back as early as 1828, when Bruton patented a system, worked intermittently. The retorts were placed in a setting, and heated externally; the coal was filled in through a gas-tight door at the top, and the coke was drawn off from the bottom; the gas was also given off at the top. In 1885 another proposition was made by Rowan, who patented a process by means of which the coke was discharged through a water-sealed bosh at the bottom, and subsequently raked out by hand. The coal was fed in through a hopper at the top, the gas being given off a little lower down. In the year 1902, Dr. Buet, of the Deutsche Continental Gasgeselschaft, applied for a patent

in Great Britain for a process of carbonisation in vertical retorts, of which fig. 236 is a vertical section ; these retorts are placed side by side in a setting ; the front part of the retort is constructed with louvre openings, C, for the purpose of drawing off the gas from all parts of the retort at the same time, and thus obviating the passage of the gas from the lower portion of the retort through the upper layers of the incandescent carbon in the retort, thus preventing the action of the hot carbon in decomposing the hydrocarbons in the gas. In order to keep these louvre openings clear, there are openings formed on the outside of the space D, where the gas is drawn off, covered by doors, marked F. Later on, however, in 1904, Dr. Buet abandoned this idea, and applied for another patent, in which the gas given off found its way to the

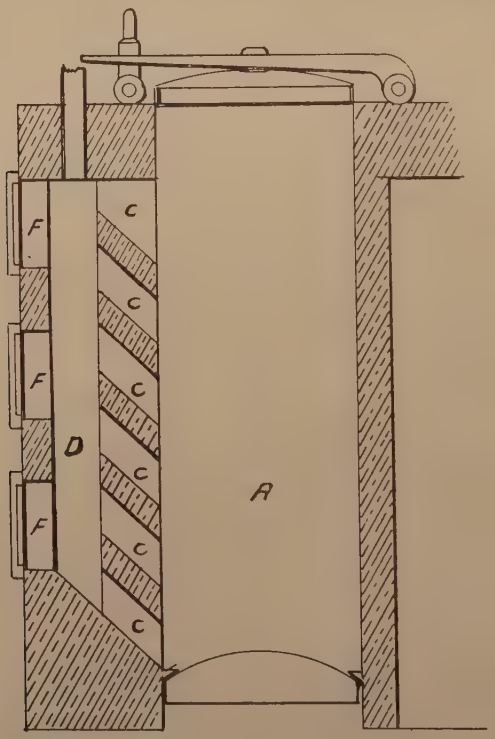


Fig. 236.—Section through " Buet " Gas Producer.

exit pipe, through the coal ; fig. 237 shows this form of setting. With a producer at the side of the vertical retorts he claims that " there is no space left inside the retorts in which tar can quickly separate from the gas," and these are so worked that the temperature of the gas is kept from rising beyond the limit of decomposition of the heavy hydrocarbons, thus preventing the formation of naphthalene. The retorts are made oval in section, and taper towards the top ; they are heated to a high temperature by the gas provided by the producer *d*, which passes into the flue *b*, constructed round and between the retorts ; these flues are divided in the height of the retorts into three tiers. The bottom of each retort is provided with a door, *a*, inside which is a projector,

c, for supporting the charge of coal and keeping it off the door during carbonisation. At the commencement of operations in this system, the retorts are heated to a high temperature, and then charged with coal up to the level of the top of the uppermost flue, and the coal is kept up to this line; carbonisation commences round the walls of the retort, the gas thus produced being forced up the comparatively cold centre of the coal in the retort, by which means the heavy tar is extracted and a light brown oil is obtained with the gas in the condensers.

Another form of vertical retort was introduced by Messrs. Settle and Padfield in 1902; it was worked as a continuous system with regard to the feeding in of the coal, but the discharge of the coke was intermittent, being performed

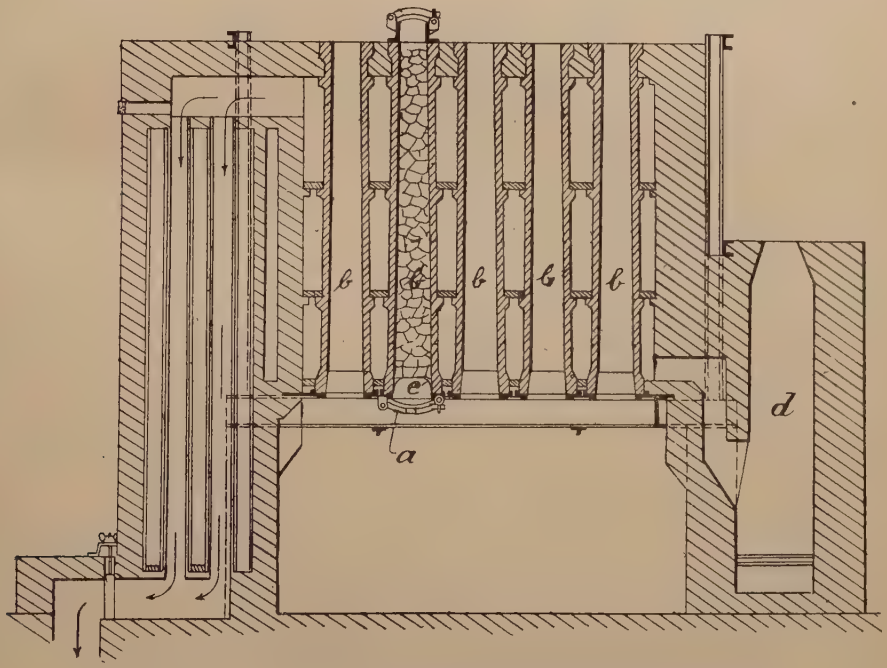


Fig. 237.—Section through "Woodall" Gas Producer and Retorts.

by hand, at stated intervals. Fig. 238 shows a vertical section through this retort setting; the retorts are placed in the setting and fed by means of an apparatus at the top, which at stated intervals allows a measured quantity of small coal to drop into the retort from the hopper Q, by means of spaced conical plungers O, whose action is such that when one of the plungers projects into the hopper Q, or the retort mouth H, the other plunger is within the tube R, to seal up the gas exit pipe. The retort, A, shown in the figure, is hung by the throat, by means of a collar, and at the bottom a similar collar surrounds it, and is built into the outside wall of the setting. The drawback of thus constructing vertical retorts is in the difficulty that is experienced in keeping the neck round the retorts gas-tight, as, owing to the expansion and contraction of the heated part of the retort not corresponding to a simultaneous expansion or contraction of the surrounding brickwork, the retorts, if made in one piece, are often cracked,

and fall away at the neck. This has been the experience with most of the early attempts at carbonising in vertical retorts, when they were made in one piece and fixed at the top. Vertical retorts are now generally made in several sections.

In 1903 Messrs. Woodall and Duckham made an advance in their proposition, patented by them, for a system of vertical retorts in which the coal is automatically fed in at the top and the coke automatically and continuously

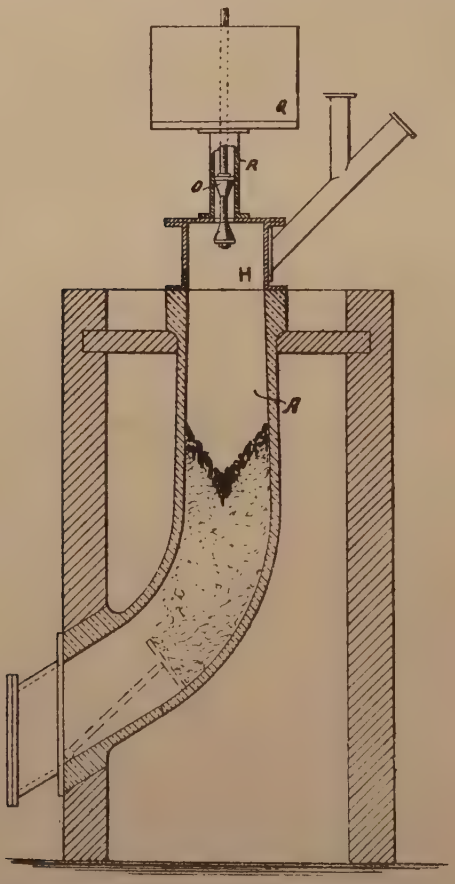


Fig. 238.—Section through " Settle and Padfield " Gas Retorts.

discharged from the bottom. Fig. 239 shows a vertical section through these retorts. The feeding apparatus consists of a drum, *e*, revolving in a cylindrical casing, *o*, and, as the opening passes the shoot, *y*, the drum is charged with small coal, which, as the opening passes the shoot, *f*, is discharged into the retort. The retort is set vertical, so that the charge may descend by gravity, the interior being slightly tapered towards the top to facilitate the descent of the charge. The retort is surrounded by heating flues, *b*, the gas for heating being introduced primarily into the top flue, *n* ; this flue will, therefore, be the hottest ;

the gas enters by the ports from the passage, *r*, where it meets with its air supply entering by the ports, *a*; the products of combustion pass downwards through the flues, *b*, to the exit flue. The air for combustion of the gas is pre-heated

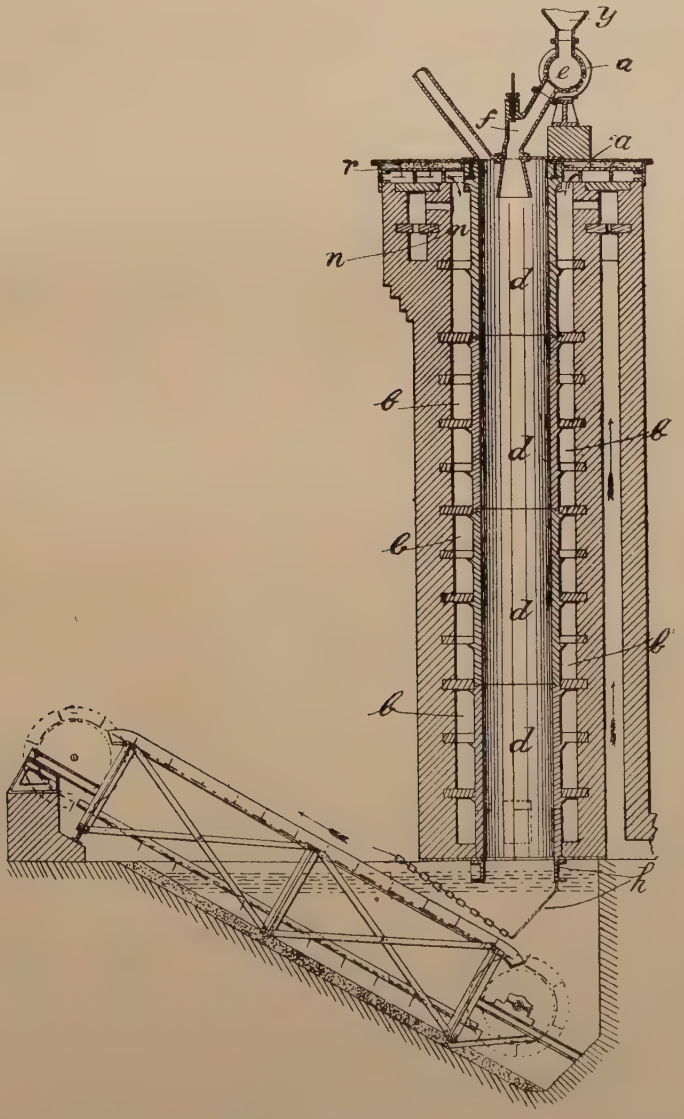


Fig. 239.—Section through " Woodall and Duckham " Gas Retorts.

by being drawn through flues placed between the top brickwork of the setting and an iron casing packed with non-conducting material. The coke is discharged into a water-bath, and removed by a conveyer; the bottom of the

retort may, however, be partly closed by a plate, *k*, worked by a chain, but which would be extremely difficult to operate, owing to the coke in the retort and in the bosh.

The steam produced by the quenching of the coke in the water of the bosh passes up into the retort for the purpose of its decomposition by the hot carbon, forming hydrogen and carbon monoxide gas. These retorts, built up in sections in the settings, were further improved by means of longitudinal ribs being moulded on to them, so as to keep them in their respective vertical position in the settings, and at the requisite distance apart; this arrangement is shown in fig. 240, where several retorts are shown in horizontal section, placed in a setting. It is evident that by heating the retort to the highest temperature at the top, trouble would be experienced in the normal working of the feeding apparatus; to obviate this, another device was introduced in 1905, by forming a tank around the top of the retort, in which water was circulated for the purpose of keeping the shoot cool. The lower edge rests in a trough fixed to the top of the retort, the joint being made gas-tight by means of packing.

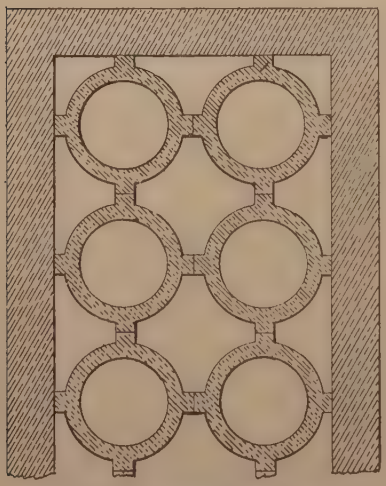


Fig. 240.—Sectional Plan through "Woodall and Duckham" Vertical Retorts.

In order to get a more uniform temperature throughout the setting of vertical retorts, Messrs. Woodall and Duckham subdivided the settings, so that the retorts were enclosed in separate compartments, the compartments usually containing two retorts each, although one, or more than two, may sometimes be enclosed in each compartment. The horizontal and vertical partitions are so arranged that the hot gases of combustion are compelled to travel through each chamber and around all the retorts. The gas main pipe has branches supplying gas to each chamber, the supply being controlled by a damper, while the air for combustion is admitted to each compartment through ports in the flues in the setting.

Messrs. Young and Glover in 1905 (B.P. 23,650) proposed a method of carbonising in vertical retorts, for the purpose of conducting the gas produced, as already described above, through the fresh charge of coal to clean it from the tarry matter; they subject the gas to radiant heat for the purpose of producing permanent gases. Fig. 241 shows this proposition in vertical section. The coal is charged into a hopper, surmounting the retorts, from which it passes into measuring hoppers, of which there is one to each pair of retorts; from these measuring hoppers the coal descends into the drying chamber A, and by the action of the rotating arms is discharged into the retorts B, these being filled to about four-fifths of their height. In this arrangement the feeding of the coal, and discharge of the coke, may be either continuous or intermittent. The coke is discharged at the bottom by a screw into a hopper. The retorts are heated by producer gas, supplied to the heating flues; the air for combustion is pre-heated by being conducted through flues running alongside the flues containing the waste gases, and adjoining the retorts. The retorts are heated

to various temperatures at various heights by the introduction of secondary air to the gas at various points, which air is regulated, as required, to produce the desired temperature; the temperature is arranged by this means to be highest at the base of the charge, and lower in the upper sections of the retort, this being the reverse of that already described in the Woodall and Duckham process. The gases given off from the charge of coal pass up through the charge, which denudes them of the tarry matter; they accumulate in the upper zone of the retort B, and are to a certain extent decomposed by the heat in this zone; subsequently they pass through the coal-drying chamber A, before leaving the apparatus. The screws discharging the coke are kept cool by water, which is sprayed subsequently on to the coke in the discharge hopper.

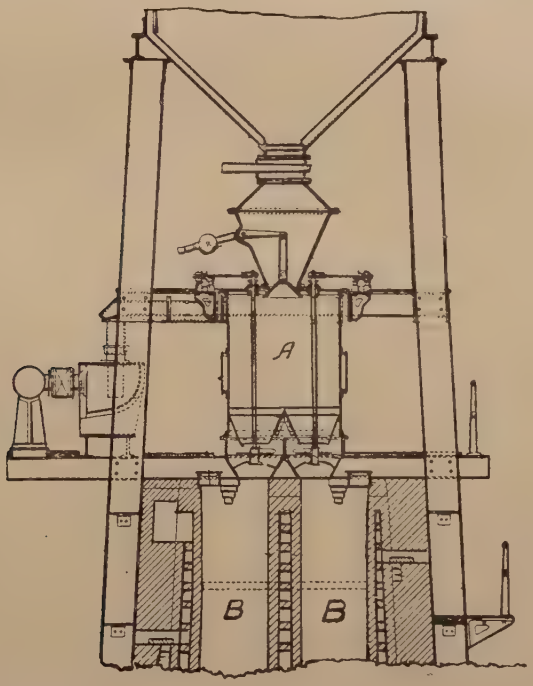


Fig. 241.—Vertical Section through "Young and Glover" Retort.

Messrs. Glover and West, in 1907 (B.P. 2,663) proposed to heat the retorts by separate combustion chambers, similar to those already referred to by Messrs. Woodall and Duckham (B.P. 12,789, A.D. 1905). These combustion chambers are controlled by means of separate dampers. Figs. 242 and 243 show this arrangement in both vertical and horizontal sections. Producer gas is used for heating the retorts, and is conducted through the flues *d*, having nozzles communicating with each combustion chamber; the products of combustion pass to the flues *g*, through which they enter the flues 1, 2, 3, situated at the upper end of the retorts, and ultimately escape to the chimney through the flue *y*; the air for combustion enters by means of the ports *b*, and becomes heated by passing through the chambers O^1 and O^2, situated round the lower ends of the retorts. The air is then conducted through the flue *e*, there gaining

further heat from the adjoining flues containing the waste gases of the products of combustion on their way to the chimney.

Messrs. Glover and West subsequently altered their process in some of its

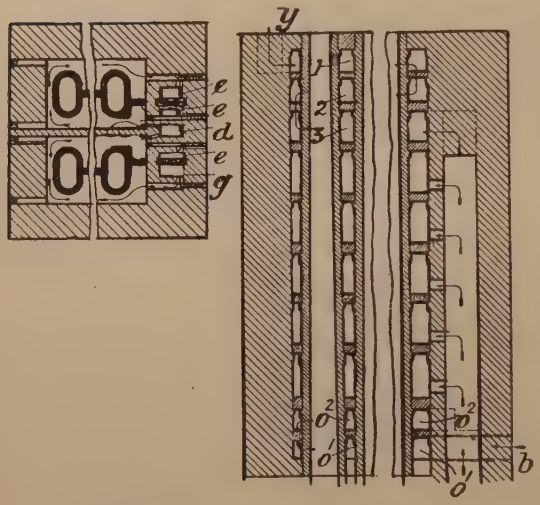


Fig. 242. Fig. 243.

Vertical Section and Plan of " Duckham " Retort.

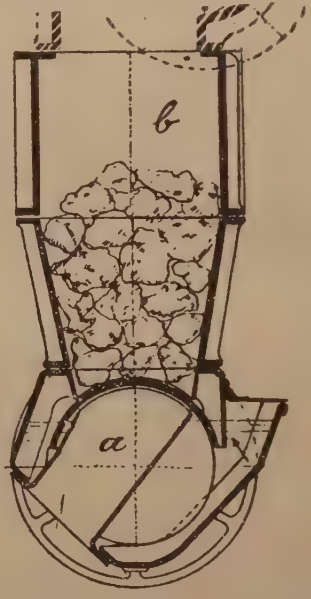


Fig. 244.—Section through Coke Discharging Apparatus (Duckham).

details, by which alterations the coal supply to the charge in the retorts is governed by the rate of the discharge of coke.

In 1907 and 1908, Messrs. Woodall and Duckham introduced their automatic coke-discharging apparatus (B.P. 15,053—1907) and (B.P. 12,070—1908). By a

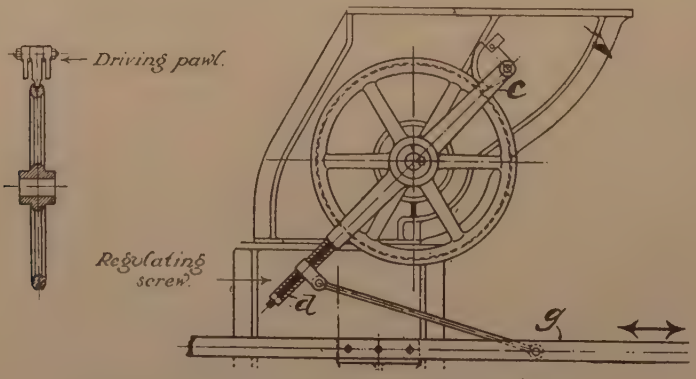


Fig. 245.—Section through Coke Discharging Apparatus.

device shown in figs. 244 and 245 the bottom of the coke-receiving hopper, fig. 244, is closed by a water-sealed gas-tight door, *a*, very ingeniously

contrived to discharge the coke periodically from the receiving hopper *b*, and at the same time keeping it perfectly sealed and gas-tight during the operation. The discharge of the coke from the retort into the coke-receiving hopper is performed by means of an "extractor roller," the shaft of which projects through a gland on each side; on one side of this shaft a grooved wheel is fitted; in the groove works a wedge shaped pawl, fig. 245, actuated by a rocking arm *c*, which may be adjusted by a screw *d*, regulating the distance of travel and controlling the amount of discharge of coke. These rocking arms are all coupled by short connecting-rods to a reciprocating bar, *g*, running along the whole

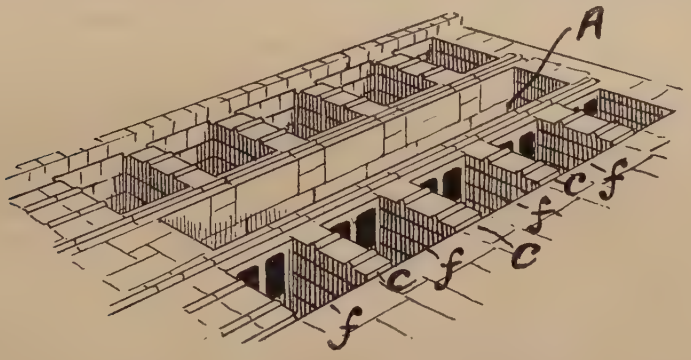


Fig. 246.—"Duckham" Vertically-Built Retorts.

length of the bench of retorts. The speed of this extractor is generally about 60 to 90 revolutions per minute. The screw adjustment gives a regulation of from 12 to 20 revolutions. The coke discharge being evenly maintained throughout the process of carbonisation, an even descent of the charge in the retorts is produced; in order, therefore, to maintain the charge at the proper level, an automatic feeding apparatus was designed, which contains the coal feeder, the gas off-take, and the regulating division plate. The coal feeder consists of a gas-tight feeding hopper mounted on a casting attached to the mouthpiece of the retort; this hopper is closed by a circular gas-tight valve, which is operated by hand every three hours; the rate of flow of the coal into the retort is regulated by a weight suspended inside the hopper and connected through a stuffing-box to an indicator outside.

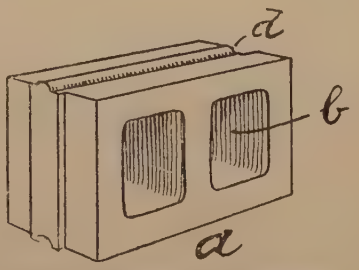


Fig. 247.—Bricks for "Duckham" Built-up Retorts.

One of the latest and one of the most important improvements relating to the carbonisation of coal in vertical retorts was made by Messrs. Woodall and Duckham (B.P. 16,630—1910). It consisted of a built-up retort on the lines adopted in the construction of coke ovens, and applied by the author for this purpose in his process for coking (B.P. 14,157—1904); the bricks used in the construction of the coking chambers or retorts were formed with a groove and tongued joint, fig. 247, the heating flues being formed in the walls with these bricks, as in fig. 246. It will be observed that the gas retort as hitherto used has been abandoned, and coke-oven construction has been substituted; the coking

retort or chamber, A, is now a tall, narrow structure, formed by means of the bricks, *a*, described above, and held together by the tongued bricks *d*, projecting into the walls, *c*, between which the vertical flues, *f*, are formed ; the bricks are made with a recess in them for the purpose of strength, as shown in black in fig. 246, but the spacing brick, *d*, dividing the heating flues, together with the walls, *c*, must absorb a great amount of the heat, which is carried away to the chimney. The recesses, *b*, in the bricks, although used for the purpose of strength, prevent the heat from reaching the inside of the retort to a greater extent than if they were made plain, and thinner in proportion.

Ascension Pipes.—The ascension pipes to carry away the gas from the retorts are connected to the socket on the neck of the mouthpiece shown in figs. 228 and 229. These pipes are carried up to the top of the setting, and

Fig. 248.—Mouthpieces and Ascension Pipes from Retorts.

bent over, and dip into the hydraulic main ; they are provided with openings on the bends for cleaning out accumulations of tar and pitch ; the end in the hydraulic main dips under the water with which the hydraulic main is partly filled, so as to form a sealed joint for the gas ; so that, when the retorts are opened for withdrawing the coke, the gas cannot get back down the ascension pipe. The hydraulic main also serves the purpose of collecting the gas in its upper portion, above the water line, and also collects the water condensed from the gas, with the ammonia it contains, as well as the tar that may also be condensed from the gas, and which sinks to the bottom of the hydraulic main.

Hydraulic Main.—The hydraulic main having to be constructed large enough for the purposes stated above is of considerable weight, and is generally supported upon steel girders, stretched across the settings, and fixed upon steel

uprights on the sides of the furnace, which are let into the concrete at the base of the wall. The hydraulic main is now constructed with steel plates, but formerly of cast iron ; the plates form a trough with a square or circular bottom and a flat top ; the top is fixed on with bolts and nuts to flanges on each side ; this main runs along the whole length of the retort settings, and receives all the dip pipes from the mouthpieces of the retorts ; the dip pipe enters the top of the hydraulic main and dips down below the surface of the water about $\frac{3}{4}$ of an inch ; the lightness of the gas allows it to bubble up through the liquor in the main. This latter is now generally constructed in sections with a branch gas pipe connecting each section to a foul gas main pipe, which is placed alongside the hydraulic main. The divisions in the hydraulic main are formed for the purpose of shutting off one section from another, in order that a certain section can stop work without interfering with another section. The tar being heavier than water sinks to the bottom of the hydraulic main; there are several processes at work in gas works for drawing off the surplus tar and keeping at a constant level the liquor floating above the tar, and as this liquid forms the seal to the dip pipes, it is necessary that it should be of a sufficient depth to keep the tar from touching the dip pipes, as the gas is not improved by passing through liquid tar, the tar absorbing some of its materials as regards lighting purposes.

Condensers.—The gas from the foul main pipe passes generally out of the retort house to the condensers ; care is taken to avoid any considerable fall in temperature in this foul main pipe. In some instances the gas is carried along the wall inside the retort house. The condensers usually adopted consist of a system of pipes laid nearly horizontally, exposed to the air, and in hot weather sprinkled with a spray of cold water. On the end of the foul main coming from the retort house is a cross pipe to which is attached several condensing pipes, ranging from 6 to 12 inches in diameter, the size and number of these pipes being determined by the make of gas ; they are formed in several tiers, one over the other. The gas passing from the uppermost pipe turns by a bent pipe into the pipe beneath it, and flows along this pipe and by a similar bend at the other end turns back again along the pipe beneath it again, and so on till the bottom is reached ; some condensers have from 10 to 12 rows of these pipes ; the pipes are laid with a slight inclination so that the tar and liquor may run out by gravitation as it is condensed from the gas.

The usual amount of condensing surface of pipes exposed to the air is about 150 to 200 square feet per 1,000 cubic feet of gas passing through them per hour.

In former times, and in some old works of small capacity, the condensers are formed with vertical pipes, but they are not so efficient as those placed horizontal. Some forms of vertical condensers have a sprinkler at the top to spray water on them in the hot weather. The condensed tar and ammoniacal liquor pass out of the lower end of the pipes into a collecting tank, common to all the vertical pipes, but having partitions in it directing the proper flow of the gas. The practice of cooling the gas gradually has been adopted in order that it may retain as much as possible of its illuminating materials, consisting of the volatile hydrocarbons ; but, with the advent of the incandescent gas mantle, now that candle power gas is no more required for lighting, but on the contrary heating power is necessary, the gas may be cooled more rapidly and economically.

There are several improvements in this direction now being applied, such as passing the gas through water-cooled pipes, or through apparatus where cold water pipes traverse the course followed by the gas.

Exhausters.—From the condensers the gas is drawn by the exhausters, and is forced by this means through all the subsequent apparatus used for its purification. The exhausting of the hydraulic main relieves the pressure on the retorts, thereby saving gas from leakage, and also preventing the deposition of carbon on the retorts at the expense of the hydrocarbons in the gas.

One of the earliest forms of the exhauster was in the form of an Archimedian screw, and used to pump the gas from a higher to a lower point, level with the surface of a small reservoir of water. "The screw revolves in an opposite direction to that required for pumping up or raising liquids, and at each revolution the upper mouth of the helicoid canal takes in a certain quantity of gas, after which flows the water. The gas descends along the spiral canal of the screw in proportion to the rate of revolution in the latter, and having reached the lower extremity of the canal, passes off by a pipe, with an excess of pressure, measured by the height of the surface of the water above the lower extremity of the screw."*

A number of years ago, when testing the advantages of exhausting the gas, Mr. Grafton is stated by Mr. Muspratt to have carried out some important experiments with a view to discovering whether the deposition of carbon in the retorts was due to pressure on the gas; he had a retort charged with coal and then had the pressure increased in it to fourteen inches of water, using coal from the Newcastle district of Walls End; he continued the carbonisation under these circumstances, with the result that in the course of a week there accumulated a carbon deposit of 1 inch in thickness in the retort; continuing the trials for two months, this deposit had filled up about one-quarter of the retort, and the weight of carbon deposited amounted to 10 cwt. and 20 lbs., produced by the carbonisation of 67 tons of coal. Reversing the process, he made some trials releasing the pressure to one half-inch of water in the hydraulic main, at the dip pipe, and under these conditions the retort was worked for four months, when scarcely any deposit had formed.

In 1866, Beale patented his invention as the pioneer of modern exhausters; an improved pattern was made by Messrs. Bryan Donkin, who acquired the sole rights of the invention in 1870, and subsequently greatly improved the Beale exhauster by lessening the friction that was produced in the first type of machine by the slides which pass through the rotating axle, guided by rings running in recesses in the endplates, which were the cause of the undue amount of friction. An improved machine, patented by Beale, is shown in fig. 249, having two blades in which the guiding rings were abolished, the guiding of the slide being performed by means of a block running on a pin fixed in one of the endplates. The travel of the block in an exhauster 3 feet in diameter, working at the rate of 80 revolutions per minute, is 70 feet per minute, whereas it amounted to 700 feet per minute when the guiding was done by means of the rings; by thus reducing the friction only one-third of the power was required to drive the exhauster.

The following figures show the several working parts of the exhauster: 1 (fig. 249) represents the cylinder, which is bored so that the vertical diameter is equal to the chord struck horizontally through the centre of the axle, and therefore below the centre of the cylinder; by this means a slide can be used in one piece, double-ended, in place of the slide in two parts, and hence with less working friction; (13) represents the axle or inner drum, which is cast in one piece with the shaft, and slotted to receive the main slide; it is turned on the outside to a size just clearing the bottom of the large cylinder. Doors are

* Muspratt's "Chemistry," vol. ii., p. 139.

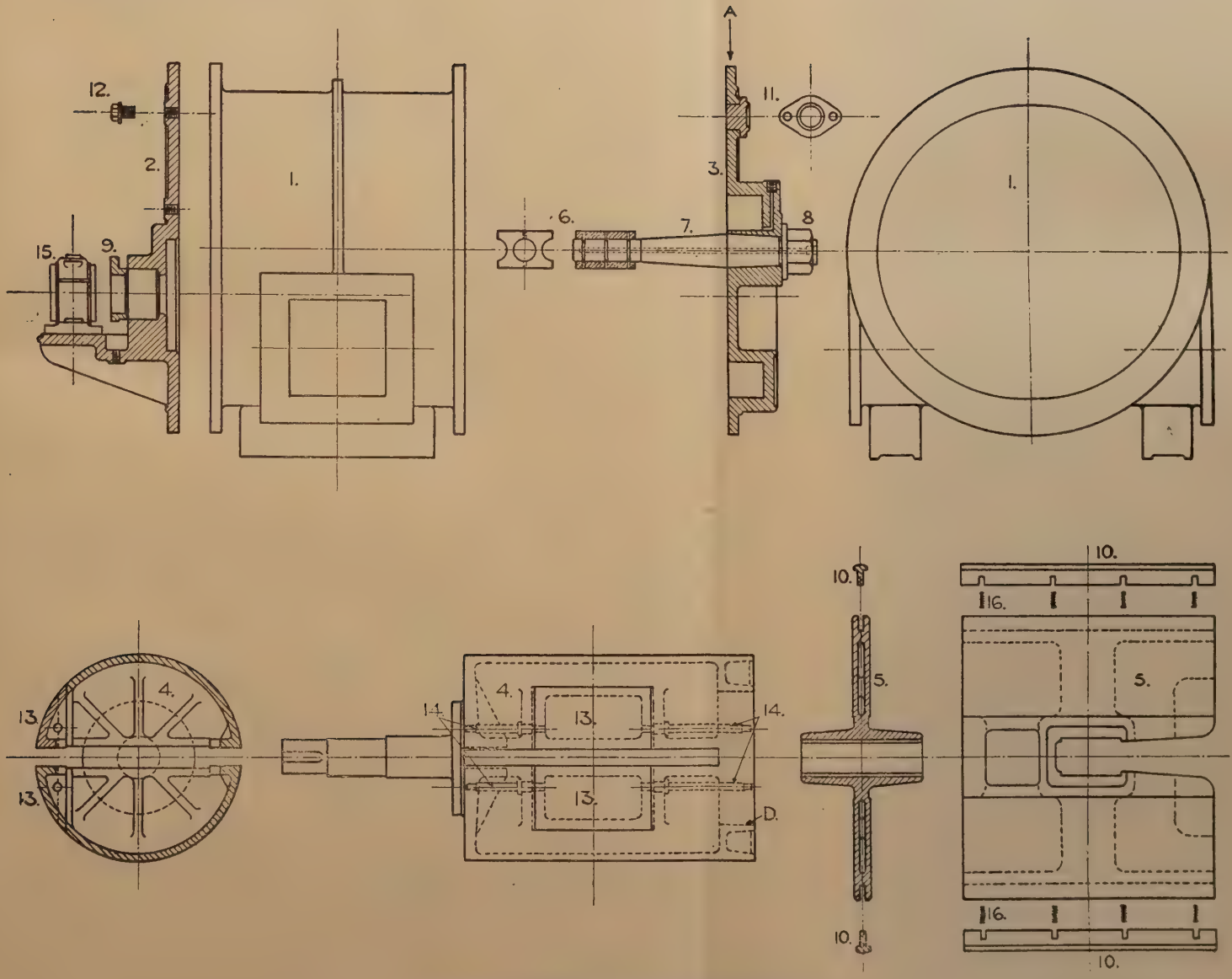
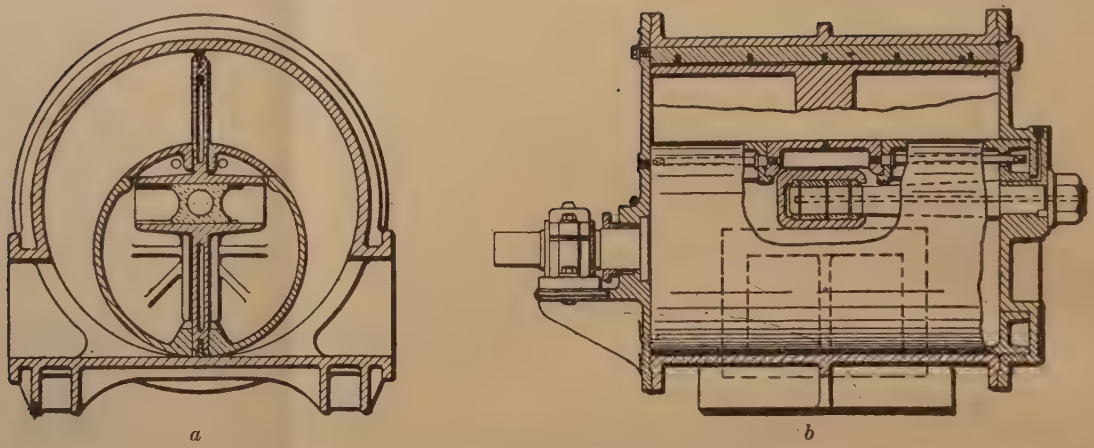
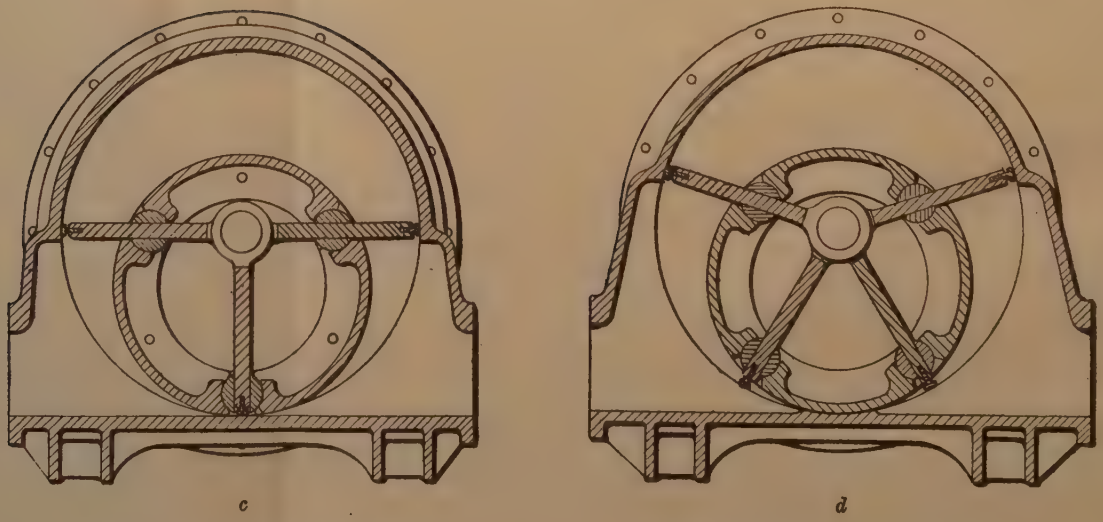


Fig. 249.—Details of " Beale " Exhauster Parts.



a *b*

Two Sectional Views of 2-Blade Improved "Beale" Type Exhauster.



c *d*

Sectional View of 3-Blade Exhauster. Sectional View of 4-Blade Exhauster.

Fig. 251.—Sections through Three Types of Exhausters.

formed in the side to permit the slide and guide bracket to enter; these are subsequently locked in position; (5) represents a section through the main slide, which is cast in one piece with the guide brackets, and slotted at each end to receive the nose-pieces (10), which are fitted into the slots with springs behind them, to keep them tight against the inner periphery of the cylinder; (6) represents the guiding block, made of malleable cast iron, and surfaced to fit accurately between the guide brackets of the slides; in guiding the slide, it rotates on the fixed pin, which is of steel, and fixed to the non-driving endplate of the cylinder. The endplate has a stuffing box fitted on it to take the driving shaft, while the other endplate contains the guiding block pin.

In order to make an exhauster practically automatic in action, it is regulated by an apparatus shown in fig. 250, which consists of a cast iron tank, containing water, in which there is a floating bell, B, which communicates with the inlet main pipe of the exhauster. The tank has a cover forming an air cushion above

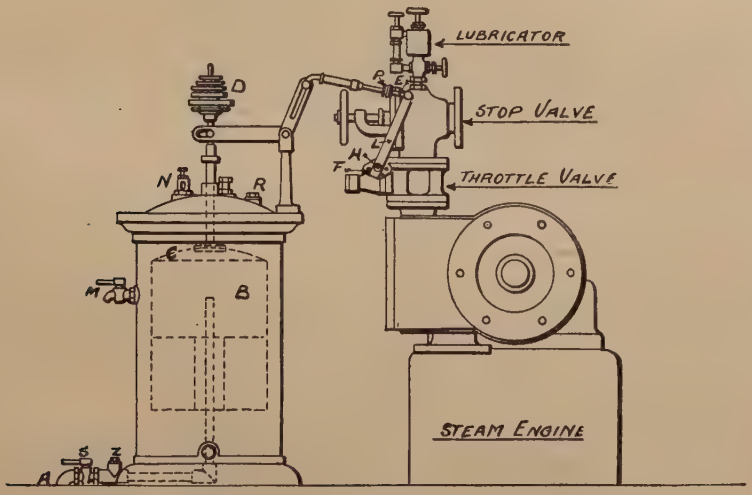


Fig. 250.—Throttle Valve Regulator for " Beale " Exhauster.

the bell, and this cover is fitted with a cock, by means of which the rate of the rise and fall of the bell can be regulated with great precision. The motion of the bell is communicated to the steam throttle valve of the engine by means of levers shown in the figure, and by which an equilibrium of pressure can be maintained to within $\frac{1}{10}$ to $\frac{1}{5}$ inch water gauge, irrespective of all normal changes in conditions of gas pressure. These regulations do not only give a constant flow of gas at practically an even pressure, but it is stated by some gas engineers that they have a very good effect on the retorts, so much so as to give a greater yield of gas per ton of coal carbonised; this is quite feasible, because any rise in pressure in the retorts gives opportunity for leakage of gas into the settings, and deposition of carbon on the retorts.

The exhauster is also supplied with a by-pass fitted with a governor whose function is to regulate the vacuum by by-passing back again the gas from one side of the exhauster to the other. Fig. 251 also shows illustrations of three types of exhausters; *a* and *b* show a two-blade Beale Type exhauster; *c* is

the section of a three-blade exhauster, and *d* is a section of a four-blade exhauster.

The exhausters of the type above described are necessarily slow in action, owing to the friction of the blades on the stationary drum.

Another type of high speed exhauster (Reavell-Haerle Patent) is a very simple and efficient solution to the problem of rapid exhaustion or compression of air or gas. This machine, fig. 252, is manufactured by Messrs. Reavell & Co., Ltd., of Ipswich, and is characterised by the insertion inside the drum of the

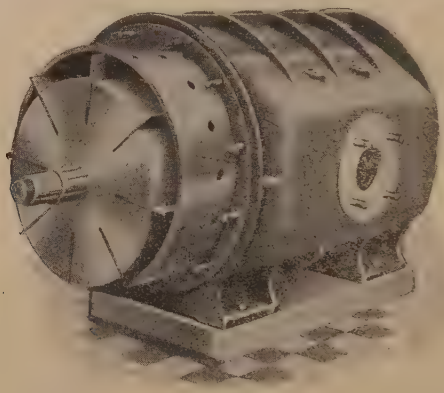


Fig. 252.—Reavell Exhauster.

older machine of another drum, which is perforated, as shown in fig 253, and inside which is placed the eccentric rotor or spindle carrying the rotating blades. When the rotor begins to revolve, the centrifugal force generated in the blades causes them to press against the inner surface of the rotating drum, and the

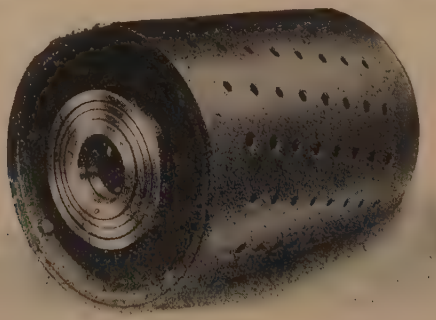


Fig. 253.—Reavell Exhauster.

latter, being free to rotate, is carried round by the pressure of the blades; this rotating drum is an accurately fitting perforated cylinder, rotating on roller bearings situated in the fixed end covers of the casing. Fig. 253 shows this perforated drum with the blades and rotor inside, the outside drum or casing being taken off; and figs. 254 and 255 show respectively, longitudinal and cross-sections through the drum and casing on a belt-driven machine. Another type of high speed exhauster made by the same firm is the "Turbo Exhauster."

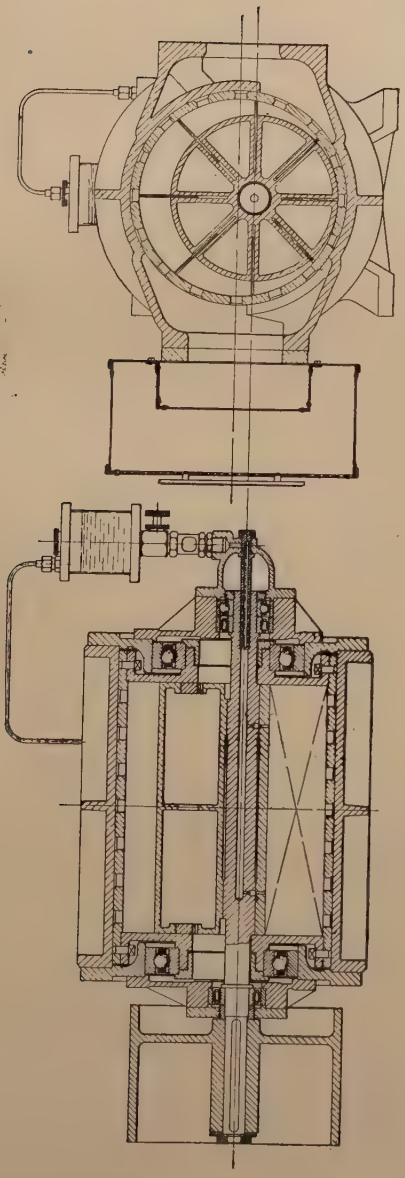


Fig. 255.

Fig. 254.

Sections through Drum of Reavell Exhauster.

Fig. 256 shows a steam turbine-driven gas exhauster for coke-oven gas, capable of delivering from 8,000 to 10,000 cubic feet per minute with a pressure, —15 inches W. G. suction, and +30 inches W. G. pressure. The Turbo-Compressor consists of two parts, the rotor and the stationary casing. The former consists

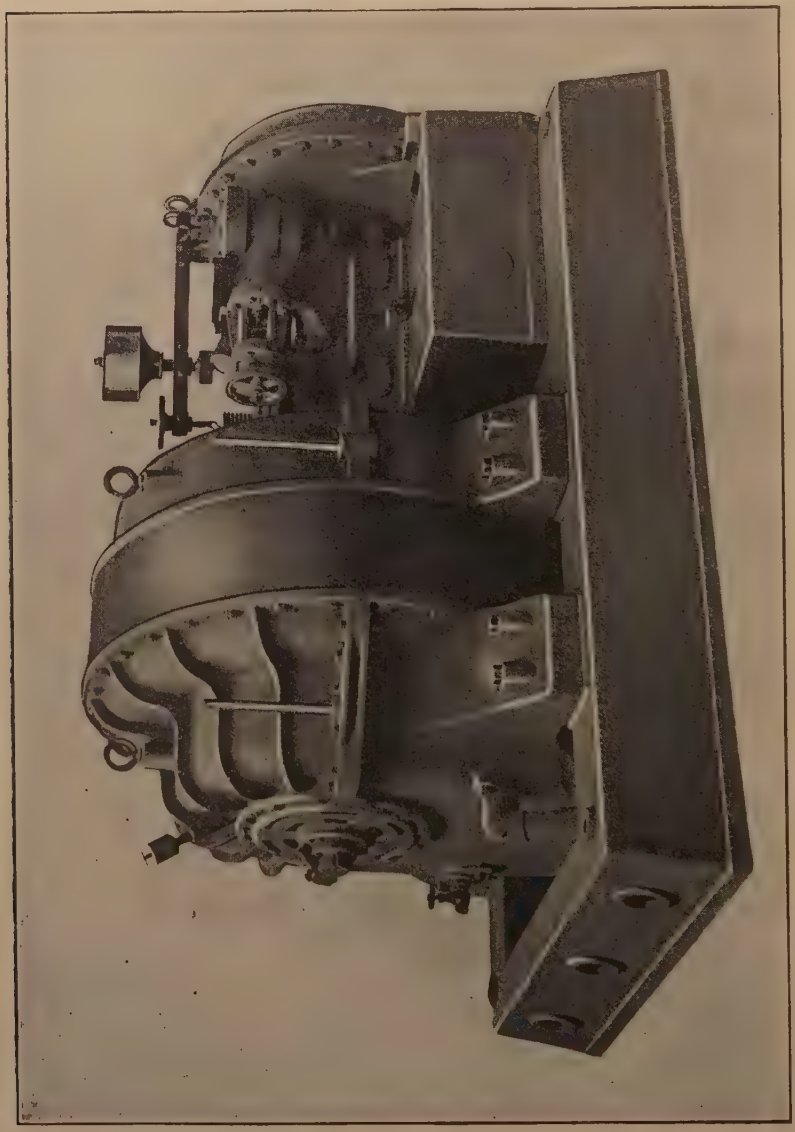


Fig. 256.—Reavell Steam Turbine-Driven Turbo Gas Exhauster, for Coke Oven Gas.

of one or more built-up impellers fitted on a shaft, running on roller bearings; fig. 257 shows a two-stage rotor, and fig. 258 the patented diffuser of the Reavell machine, the position and form of the diffuser blades being shown, which are made from thin flexible metal to suit the nature of the gas that has to be

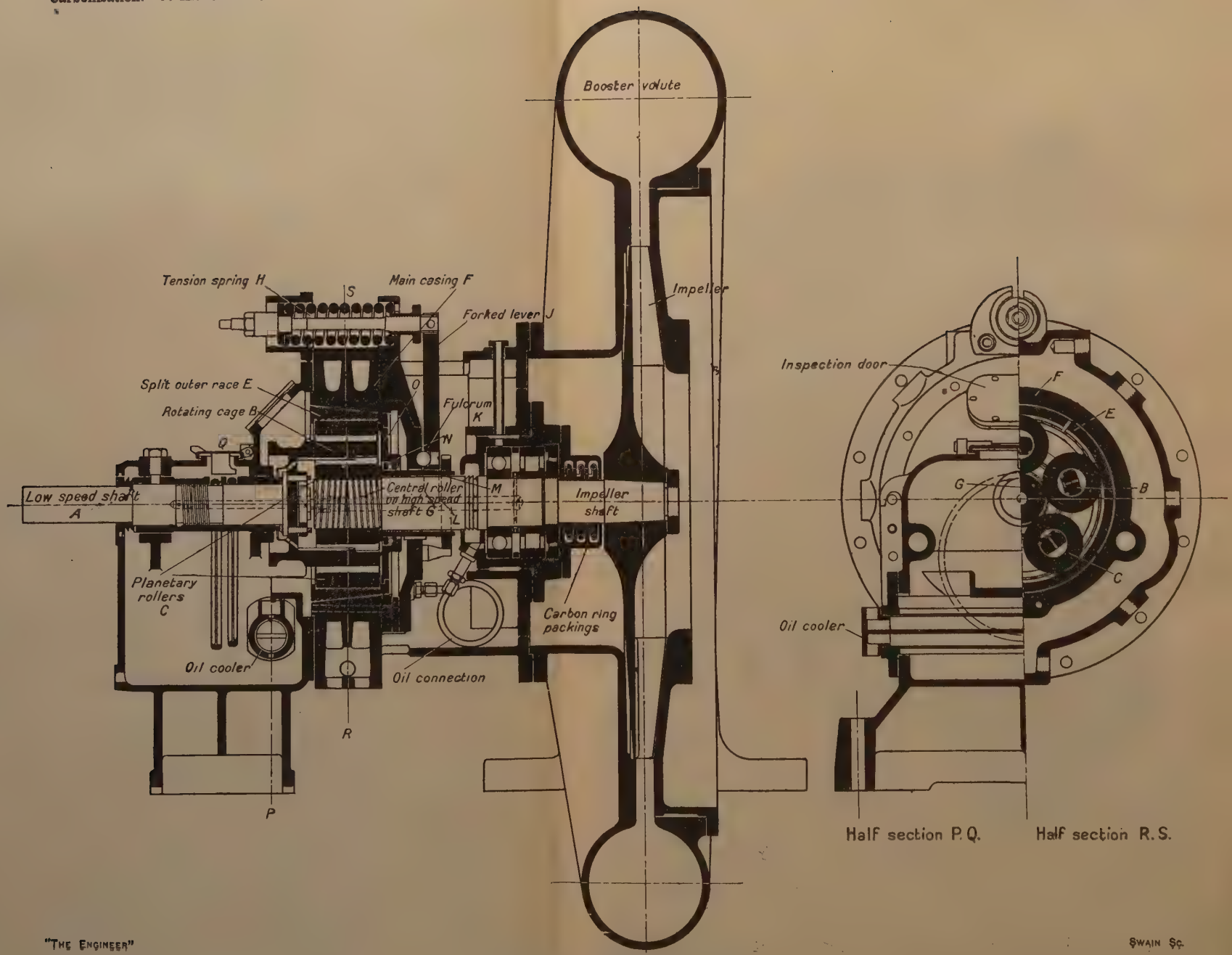


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Fig. 259.—Reavell Turbo Gas Booster.

exhausted; it will be seen that the gas passing these blades is converted by the energy of its velocity into actual pressure. The gas Booster is another type of high speed gas exhauster. Fig. 259 shows this Booster fitted with Matteucci gear, as working at the Poole gas works of the Bournemouth Gas and Water Company.

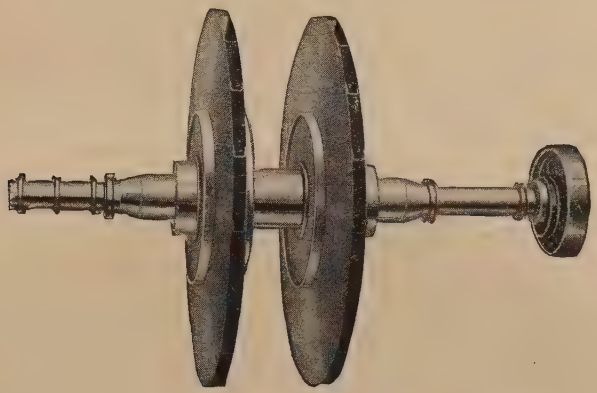


Fig. 257.—Rotor of Reavell's Two-Stage Compressor.

Fig. 258.—Patent Diffuser of Reavell's Compressor.

Gas Scrubbers.—Where the indirect process of ammonia extraction is practised, gas scrubbers are erected in which water is used to extract the ammonia from the gas, by a process of washing. The problem has been to accomplish this operation successfully with the minimum quantity of water, because, to recover the ammonia in concentrated form, all the water used has to be evaporated, and this is an expensive process. The water is therefore utilised in the apparatus in such a way that the ammonia solution leaves in a very concentrated form

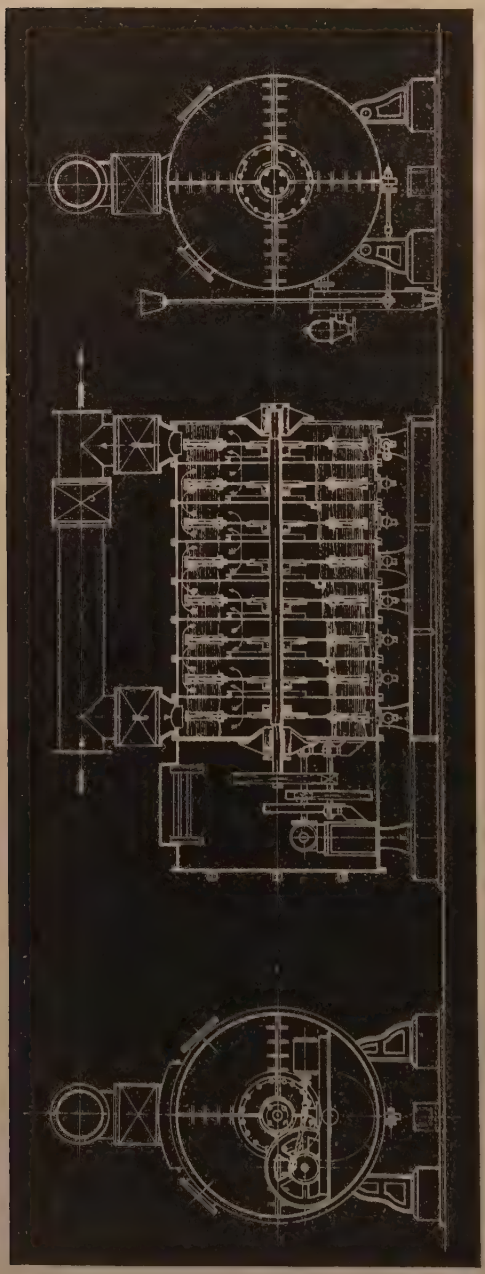


Fig. 260.—"Holmes" Horizontal Gas Washer Scrubber.

that may be further treated for pure ammonia. The apparatus used in the gas works and also at coke ovens, is generally of two distinct types, the vertical and the horizontal.

In old gas works the vertical tower is packed with coke or filled with wooden chequer work, down which trickles the water from a spray at the top, and up which the gas travels, giving up its ammonia and other salts to the water; as the water descends it takes up more ammonia on meeting the more saturated incoming gas, while the washed gas near the top meets with the weaker liquor. These old tower scrubbers are now mostly discarded for the more modern washer-scrubbers.

Fig. 260 shows a horizontal form of brush washer-scrubber by Messrs. Holmes of Huddersfield. Other makers manufacture washer-scrubbers which may differ slightly in detail, but may be as efficient in their operation; those

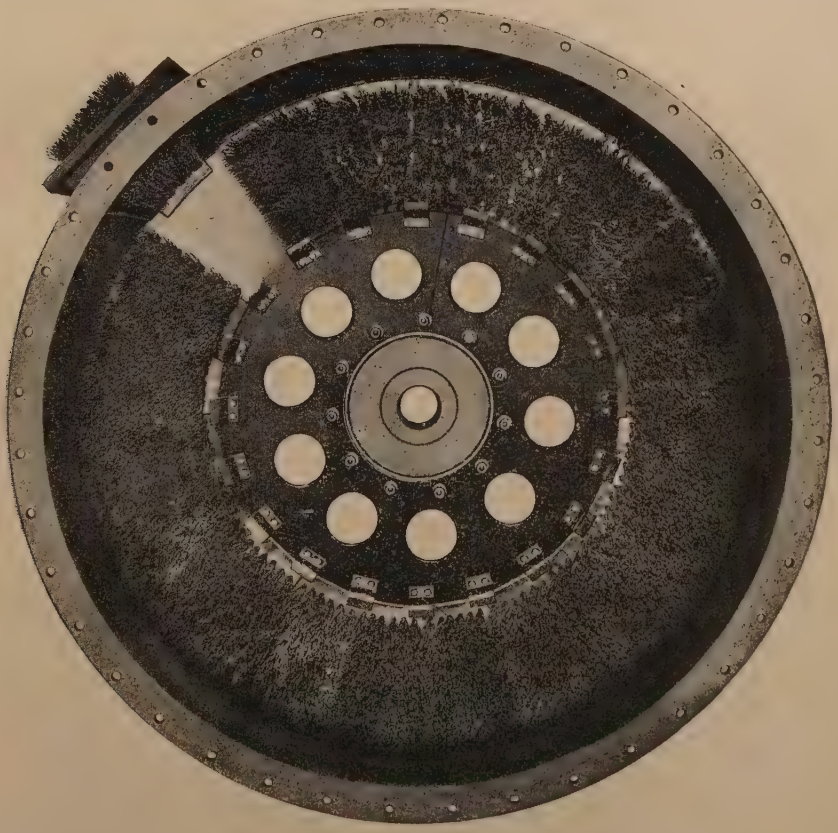


Fig. 261.—Vertical Section showing Interior Brush of "Holmes" Horizontal Washer.

illustrated are shown as a type of this class of scrubber. The patent scrubber-washer of the above firm has been very successful in efficiently washing the gas and in dealing with a very large volume per machine per day. These scrubber-washers are mechanically driven, and consist of an apparatus in which are flat discs with fixed bundles of Brazilian fibre; fig. 261 is a horizontal section showing a single chamber of the Patent Rotary Washer, with a segment of the brush partly withdrawn through the manhole when cleaning or repairs are necessary; the brushes circulate against the sides or faces

of the sections of the scrubber, which can be made with any convenient number of sections. The gas has to find its way through the interstices between the fibres, which by their revolution are constantly kept moist by the liquid in the bottom of the washer; between each compartment there are inserted what are styled still chambers where there are no scrubbers, but where the

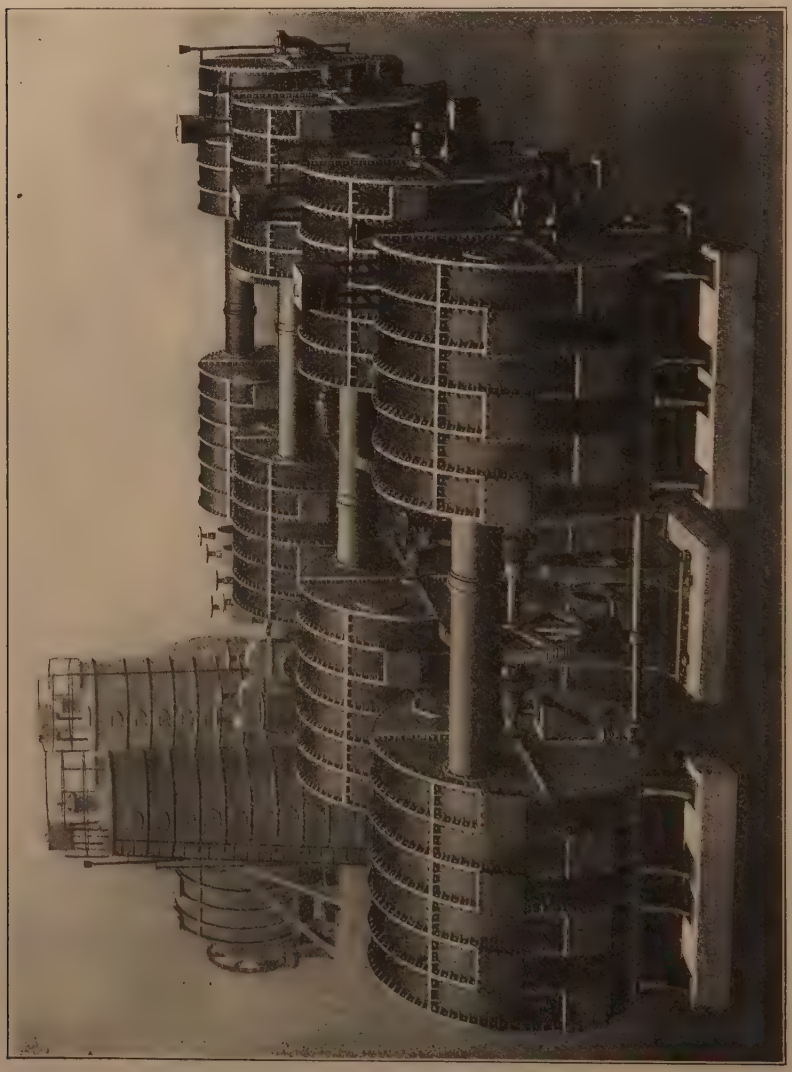


Fig. 262.—"Holmes" Washing Plant at Glasgow Gas Works.

liquor is passing from one compartment to another; these help to reduce the difference in strength between the liquors in the various compartments; there is also provision made at the bottom of each compartment for trapping off any tar or other dense matter; it is run off by means of a pipe. This washer has attained a very high efficiency in the extraction of ammonia from the gas.

Fig. 262 shows the installation of this washer-scrubber at the Provan Gas Works, Glasgow, with a capacity of 20,000,000 cubic feet of gas per day.

Carburetted Water Gas.

Water is an oxide of hydrogen, and when the oxygen is removed hydrogen gas remains; hydrogen is a gas of great heating power, but is non-illuminant. When steam is passed through incandescent carbon, maintained at a temperature of about 1,200° C., it is decomposed; the hydrogen is separated from the oxygen, the latter gas having a greater affinity for carbon at this temperature than for hydrogen; the carbon is oxidised to CO, and this latter gas, mixing with the hydrogen, is termed "water gas." Water gas is non-illuminating, and cannot be used for lighting purposes unless in conjunction with incandescent mantles; even then it is not very successful, but when mixed in certain proportions with coal gas, it gives entire satisfaction for modern lighting with mantles made from the rare earths. When it was first manufactured it was enriched with oil gas, so that a gas could be distributed with the normal candle power for lighting purposes; however, now that candle power gas is no longer necessary, the water gas as it is made is simply mixed with the ordinary coal gas and delivered into the distributing mains. It is a heating gas, and as the present requirements of the public can be met with this class of gas for heating, cooking, and various other operations, as well as for lighting, using incandescent mantles, its manufacture is now carried on in almost every gas works in the country. Some correspondence in the press with regard to mixing this gas with ordinary coal gas has given rise to a certain amount of prejudice against it, as being dangerous; it is true that carbon monoxide gas is extremely poisonous, and if not mixed with some other gas with a strong odour it becomes very dangerous to life, if it escapes, since it is odourless; but the number of fatal accidents directly responsible to poisoning by gas are very few. Carburetted water gas is manufactured by the gas companies from the coke drawn from the retorts; this is placed in an apparatus consisting of a vertical producer, in the intermittent system of producing the gas; it is lined with firebrick and charged with coke from the retorts. The producer resembles an ordinary gas producer, but instead of the process being conducted in a continuous manner, it is carried on intermittently, by alternate blowing in of atmospheric air, and then steam, through the incandescent coke for periods limited to a few minutes. During the first part of the process the carbon of the coke is burned by blowing into the producer atmospheric air, this producing an exothermic reaction, with a high temperature; the heat lost is that carried away by the escaping producer gas, in addition to other losses due to radiation. The second part of the process consists in shutting off the air blast and turning on the steam; this latter produces an endothermic reaction, $C + H_2O = CO + H_2$, and this rapidly extracts the heat from the carbon in the coke, which becomes latent in the $CO + H_2$ gas produced. In a few minutes the reaction, if allowed to continue, changes its chemical nature, due to the reduction in temperature; the reaction between the steam and the carbon produces, instead of $CO + H_2$ (the gas desired), $CO_2 + 2H_2$, a useless mixture. The formation of hydrogen and carbon monoxide from steam proceeds at a temperature of about 1,200° C., and should the temperature drop to 1,100° C., slackens off, and the reaction producing CO_2 commences, until the temperature falls below 700° C., when the monoxide-producing reaction is practically stopped, and the reaction is almost entirely

$C + 2H_2O = CO_2 + 2H_2$; if the temperature is allowed to fall further, the steam passes through the apparatus practically unchanged. With these facts in view, the process has to be reversed, and for a period, combustion of the coke must be stimulated, and heat developed by blowing in atmospheric air. The greater the amount of heat produced at a blow with the air blast, the more steam can thereby be decomposed in the second operation, which is carried on until the temperature falls below 1,000° C., when the presence of too much CO_2 becomes apparent. Mr. Butterfield, in treating this subject, has worked out five possible reactions that may take place in the generator, all of them depending upon the temperature, and upon the state of the carbon in the producer. For the proper production of water gas, practically free from CO_2, which is the gas to be avoided, it is absolutely essential to have a deep bed of fuel; the steam pressure and its volume must also be controlled; the coke in the generator must also be of the proper size; when these conditions are not fulfilled, the counter reactions arise. When the coke forming the charge is not deep enough and is in too large pieces, the steam may be forced through it without being completely decomposed into H_2 and CO, and CO_2 may be found in considerable quantity. One of the difficulties attending the manufacture of water gas is the thorough heating of the mass of coke in the generator; when this is performed by blowing air into one of the ends of the generator containing more than 12 inches in depth of coke in small pieces, the high temperature produced by the oxidation of the carbon is local, and as the CO_2 formed by the blow passes higher up into the bed of coke, it is decomposed by taking up an additional atom of carbon, but this reaction is endothermic and the temperature is thereby reduced to about 750° C. Hence, unless the blast can be made to penetrate beyond the zone of this reaction, the carbon will remain at the low temperature, and the reaction of the steam to make pure water gas will be confined to the local portion of the coke at the high temperature only; the portion of steam that passes to the upper region of 750° C. will not produce the ideal gas required, but will be very greatly contaminated with CO_2 gas. This suggests, therefore, a thin bed of fuel for the proper heating, whereas for the purposes of the decomposition of the steam a thick bed of highly heated fuel is demanded. The penetration of the blow depends upon the size of the pieces of coke; if they are small the heat of 1,200° C. will not penetrate so far as if the pieces were of larger size. The ideal form of producer or generator for the manufacture of pure water gas—that is, for the production of H_2 and CO—would be one in which the carbon in the producer was blown in such a way that only CO_2 was formed; then the steam applied for only so long a period as the above pure gas was given off, and the steam valve closed immediately the temperature fell to the point where the counter reaction commenced. Such a process would be the most economical, because the production of carbon monoxide, mixed with nitrogen, "producer gas," is not always convenient for use on the spot, whereas the production of CO_2 and nitrogen, leaving the producer at a high initial temperature would, in many ways, be convenient, for example, as a source of initial heat for raising steam or for superheating it previous to blowing it into the charge in the generator. These principles have been carried out to a large extent in the process of making water gas by the Dellwick-Fleischer system. A comparison with the old system of producing CO during the air blow was described in a paper read before the Iron and Steel Institute by Carl Dellwick in May, 1900, from which the following interesting statement is extracted:—

"The process of water gas manufacture consists in the alternate heating of

a bed of fuel to incandescence by means of an air blast, and the subsequent decomposition of the fuel with steam.

" In all processes hitherto used, both of these periods have yielded combustible products. The generators may vary in form and size, using the air-blast in several ways, but the chemical reaction is the same, viz. :—a combustion to carbon monoxide ; the gas leaving the producer generally consisted principally of carbon monoxide and nitrogen. The problem, therefore, was to find a use for this producer gas ; the difficulty of finding a use for it in the same proportion as it is generated has, in fact, formed one of the most serious obstacles in the way of the introduction of water gas. Various devices have been resorted to for the purpose of utilising the producer gas for increasing the yield of the more valuable product, water gas ; for example, pre-heating the air or steam, or both, for the water gas generator. All such arrangements have, however, proved more or less ineffective, besides complicating the apparatus, and the ordinary practice in the production of ' blue ' water gas has therefore been simply to use the producer gas to generate the steam.

" The radical difference between the old process and the one I have devised is that while in the former the gas leaving the generator during the ' blow ' consisted principally of carbon monoxide in addition to the inevitable nitrogen, in the latter it consists principally of carbon dioxide and nitrogen."

Dellwick then goes on to give some of the data obtained in the chemical reactions for the process of making water gas : —18 lbs. of steam, consisting of 2 lbs. of hydrogen and 16 lbs. of oxygen, require for their decomposition $2 \times 28{,}780 = 57{,}560$ thermal units. The 16 lbs. of oxygen combine with 12 lbs. of carbon to form 28 lbs. of carbon monoxide, together with 2 lbs of hydrogen, forming 30 lbs. of water gas, or equal to 753·4 cubic feet. The heat developed by the formation of the carbon monoxide is $12 \times 2{,}400 = 28{,}000$ thermal units, thus leaving a balance of $57{,}560 - 28{,}800 = 28{,}760$ thermal units, which must be replaced by the combustion of the carbon during the blow. Assuming that the producer gas leaves the generator at about 700° C., we find :—

	Old Method.	Dellwick Method.
1 lb. of carbon requires for combustion,	to CO :—$\frac{8}{12}$ lb. O_2.	to CO_2 :—$\frac{16}{12}$ lbs. O_2.
This oxygen is accompanied by . .	2·16 lbs. N_2.	4·32 lbs. N_2.
The products of combustion carry away at 700° C., ...	1,136 thermal units.	2,092 thermal units.
The heat of combustion of 1 lb. of carbon is	2,400 thermal units.	8,080 thermal units.
The balance available for heating the fuel is therefore, ...	2,400—1,136=1,264 thermal units.	8,080—2,092=5,988 thermal units.
To fill the balance of 28,760 thermal units in the production of 30 lbs. of gas there must be burned, . . .	$\frac{28{,}760}{1{,}264} = 22{\cdot}75$ lbs. carbon.	$\frac{28{,}760}{5{,}988} = 4{\cdot}83$ lbs. carbon.
Not counting the heat lost by radiation and other causes, there are then required for the production of 30 lbs. = 753 cubic feet, of water gas, . . .	12 + 22·75 = 34·75 lbs. carbon.	12 + 4·83 = 16·83 lbs. carbon.
Or, per 1 lb. of carbon are obtained, .	21·7 cubic feet water gas.	44·7 cubic feet water gas.
As water gas of theoretical composition contains 167 thermal units per cubic foot, there are utilised in the water gas from 1 lb. of carbon, . . .	3,627 thermal units, =44·8 per cent. of the heating value of the carbon.	7,465 thermal units, =92·5 per cent. of the heating value of the carbon.

In the old water gas processes the producer gas formed during the "blow" is amply sufficient for generating the steam required for the process, though it has not always been so used. When a combustion to CO_2 is effected in the generator, this advantage is of course lost, the waste heat being only sufficient for pre-heating the feed water for the boiler. It is, therefore, necessary in this case to add to the fuel used in the generator for boiler fuel 12 to 15 per cent. This reduces the theoretical quantity of gas obtainable from 12 lbs. of carbon to 656 cubic feet, and the possible utilisation of the heating value of the fuel to about 80 per cent. The water gas obtained in practice is of somewhat different composition from that theoretically calculated, and its calorific power is about 158 thermal units per cubic foot. If the coke averages 7,000 thermal units per lb., then the utilisation of the heat by these processes is 28 to 36 per cent.

Professor Vivian B. Lewes states with reference to the Dellwick water gas tested by him :—"One thousand cubic feet of water gas containing 15 lbs. of carbon are obtained by a total expenditure of 29 lbs. of carbon, so that over 51 per cent. of the carbon is obtained in the gaseous form, while the expenditure of the other 49 per cent. results in the hydrogen of the water gas. The coke used in the experiments made contained 87·56 per cent. of carbon, or 1,961·3 lbs. per ton, equal to 15,876,307 thermal units (° C.), and this amount yielded 77·241 cubic feet of water gas. The specific gravity, as taken by the Lux balance, was 0·5365, and the gross calorific value, as determined in Junker's calorimeter, was 4,089 thermal units. Hence the calorific value of the water gas from a ton of coke was 13,033,059·8 thermal units, or over 82 per cent. of the heating value of the total coke used in both generator and boiler.

"From this calculation 20 per cent. of the coke has been taken as used for raising steam, but in a large installation this figure could be reduced, and the percentage of the total heating value of the coke obtained in the gas slightly raised. The labour needed is less than with the ordinary process, as less fuel has to be handled." Other tests were made with similar results by Professor Bunte of Karlsruhe, Professor Lunge of Zurich, and Dr. Leybold of Hamburg. Carl Dellwick also states that continued work by this process at the gas works of the Corporation of Königsberg, in Prussia, gave a yield of 38·44 to 39·72 cubic feet of water gas per lb. of carbon contained in the coke charged into the generator.

The method of working the generator is quite different in this method compared with the ordinary method. In the latter the duration of the air "blow" lasts from 10 to 15 minutes, while the water gas was made during the following 4 to 5 minutes; "in the Dellwick generator the blow lasts only one and a half to two minutes, while water gas is subsequently generated for 8 to 12 minutes. During the blow the combustion continues throughout the entire depth of the fuel, and the whole bed of fuel is thus raised to an even high temperature, enabling the periods of water gas production to be considerably lengthened, without any deteriorating effect on the quality of the water gas. Fig. 263 shows the Dellwick Fleischer generator; on a level with the clinkering doors is the grate supporting the fuel; below are ash doors; the air enters by the blast valve, and the blow gas leaves the generator by the central stack valve, through which the fuel is also charged. There is one water gas outlet at the top of the generator, and one below the grate; both are connected with a three-way valve through which the gas passes on to the scrubber. There is a steam pipe leading to the bottom and another to the top of the generator. The method of working is stated to be as follows :—"A fire having been built on the grate, the generator is filled to

the proper level with coke, the blast-valve opened, and the fuel raised to a high degree of incandescence in a few minutes. Then one of the outer gas outlets, the upper one for instance, is opened, the blast and stack valve being simultaneously closed by means of the gearing on the working stage. Steam is then admitted to the bottom of the generator, and, passing up through the bed of incandescent coke, is decomposed, forming water gas. A set of water gauges and a test flame indicate the condition of the apparatus, and the quality of the gas. When the temperature falls below the point where carbon dioxide forms

Fig. 263.—Dellwick Gas Producer.

in a larger proportion, the steam is shut off, and the stack valve opened, the gas valve being simultaneously closed. The blast valve is then opened for another period of blow lasting 1½ to 2 minutes. For the next period of gas making the lower gas outlet is opened and steam admitted above the fuel. By thus reversing the direction of the gas-making, the temperature of the fuel is equalised."

Water gas possesses quite different properties from producer gas; its composition averages :—

Hydrogen,	51·0	per cent.
Carbon monoxide,	42·0	„
Marsh gas,	0·5	„
Carbon dioxide,	4·0	„
Nitrogen,	2·5	„
Total,	100·0	„

To show the increased rate of the formation of carbonic acid gas in the water gas, Butterfield states that he made certain observations at the plant working at the Southall works of the Brentford Gas Company, and found the following :—

" During the first	minute of run,	0·66	per cent.*
„	second „	„	0·77	„
„	third „	„	1·08	„
„	fourth „	„	1·32	„
„	fifth „	„	1·82	„
„	sixth „	„	2·47	„
„	seventh „	„	3·42	„
		Mean =	1·65	„

" The unpurified carburetted water gas made at the above works had an illuminating candle power of about 22 prior to purification, and as analysed by Butterfield its composition was :—

Hydrogen,	35·17	per cent.,	by volume.
Carbon monoxide,	33·92	„	„
Methane,	13·58	„	„
Hydrocarbons absorbable by fuming Sulphuric acid,	12·83	„	„
Hydrocarbons, paraffins other than methane,	1·20	„	„
Carbonic acid gas,	1·54	„	„
Nitrogen,	1·76	„	„

" The generator employed at the Brentford Gas Works is of the Lowe type. Another type of apparatus for making water gas on similar lines to those outlined above, while treating of the ideal producer, is that proposed by J. C. H. Kramer and J. G. Aarts (B.P. 2,750, 1901), in which two generators are used, together with two regenerators ; fig. 264 shows a section through one of the generators of this apparatus ; water gas is made by blowing steam alternately through the two generators containing incandescent fuel, which is covered previously with fresh fuel. The gas produced is first conducted through two regenerators, then down through the second generator. For the blowing-up period the blast enters the economiser *a*, by the tube *b*, and passes by the tube *c* to the generator, being led by other branch tubes to the spaces above and below the fuel. The heat passes to the regenerators and the gases escape through the open valve *e*, and the economiser *a*. By observing the heat through a window, the regenerators are kept at the proper temperature ; the valves are all changed, and fresh fuel is admitted from one of the hoppers to the generator. Steam is now admitted to this generator by the tube *c*, below the bars, and the water gas produced partly gasifies the fresh fuel, the moisture passing through the first regenerator to the chamber *g*, then proceeding downwards through the second regenerator and from the second generator to the outlet to the purifiers. When the temperature falls sufficiently, the valves are again reversed, a fresh blowing period takes place, after which the other generator receives the steam, and so on. By this means the fuel bed can be reduced so that the blowing period can

* *Vide* paper read before the Institution of Gas Engineers (*Journal of Gas Lighting*, lxxxii., 1,299).

thoroughly heat it without the production of CO, using the series of generators the steam blow operates on all the beds of fuel one after the other. The carburetting of the water gas is accomplished by means of apparatus attached to the generators, and the product is virtually a mixture of oil gas with the water gas. Several types of plant have been prepared and worked with more or less success; one of the first and best-known types is the Lowe apparatus. The object of carburetting the water gas is for the purpose of raising its illuminating power, and is performed by means of a carburetter, an oil heater, and a superheater. The oil heater, situated in the exit pipe of the gas to the scrubber, generally consists of a tube or a series of tubes through which the oil passes to the carburetter, where it is sprayed upon the packed brickwork in the interior; the hot water gas from the generator traverses the carburetter, and taking up the gasified oil carries it to the superheater, where it is converted into a permanent gas, and mixed with the water gas; it is then passed into the scrubbers. Another apparatus for the manufacture of gas which has had a large application is the "Tully Gas Apparatus."

Professor Vivian B. Lewes proposed, in 1897, to produce gas consisting of a mixture of carbon monoxide, hydrogen, and methane, B.P. 17·749, by injecting tar and other hydrocarbons into a producer filled with incandescent coke; the resultant gas, after it had been scrubbed and purified, was enriched by passing it through an acetylene generating apparatus. The tar in this case is injected into the producer by means of steam, about midway up in the fuel.

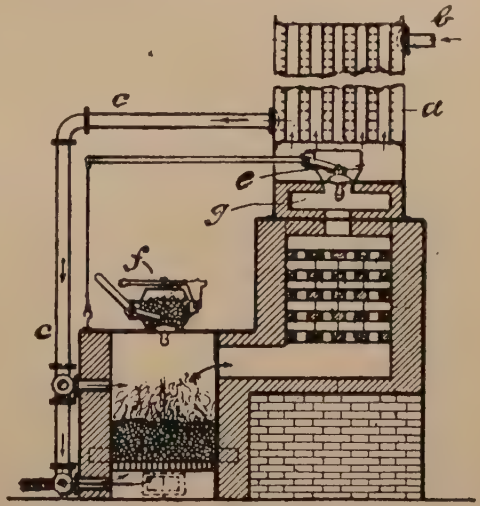


Fig. 264.—Section of "Krams" Gas Producer.

In 1901 Prof. Lewes and C. B. Tully proposed to make gas by means of a producer in which the gas is abstracted from the top of the fuel by means of a pipe, and also from a position about midway in its height by means of several outlets which are connected by another pipe to the first pipe mentioned above. The producer is fed from the top, and steam and tar are supplied by means of several jets to the producer, just below a contraction in the body of the producer, and below which are a number of tuyères supplying air and also provided with steam nozzles formed in their interior. The fuel lies on a solid bed and the producer at this part is provided with clinkering doors just above the floor.

Should the gas be extracted from the lower openings, the tar produces solid carbon particles in the form of lamp-black, which are extracted by suitable jigging apparatus, but should lamp-black not be required the gas is taken off through the upper outlet, and as the tar has to pass, therefore, through the extra mass of incandescent carbon in the producer, it is entirely decomposed and converted into gas.

A modification of this process is also provided by B.P. 15,194, by C. B. Tully, where steam and tar are also injected into the incandescent fuel in the

producer, the resultant gas being subsequently passed through a carburetting apparatus, heated by means of the waste heat and gases produced during the air-blowing period. Other modifications of producers and apparatus for the decomposition of steam and tar were made by Mr. Tully, B.P. 10,346, A.D. 1907, and in 1916 he designed his latest type of producer for manufacturing gas from coal or coke, and in which a very novel idea was incorporated by constructing an annular chamber around the producer, filled with iron oxide, into which the blow gases fron the producer are passed to reduce the oxide ; after this operation the air is shut off and steam is passed through the superheater and then through the reduced oxide for the purpose of producing hydrogen, which may be taken off direct or passed through the incandescent fuel, where the excess of steam is decomposed, producing additional hydrogen and carbon monoxide gas.

The Tully generator consists of a generator, a wash box, a blower, and a boiler for producing steam. The generator is constructed with an internal space for holding the fuel ; this is surrounded by a compartment filled with chequer brickwork, forming a superheater, through which the exhaust gases are passed for the purpose of heating it up during the period of blow ; a secondary air inlet is inserted near the base of this compartment. During the period of gas production, the gas is produced in the lower part of the producer, and is then passed through the hot chequer brickwork, where it is mixed with the rich gas coming from the upper part of the producer or " retort." It is also proposed to enrich this gas by means of carburetted oil gas. When used as auxiliary to a coal-carbonising gas-producing plant, it is claimed that " an economy of about one-third of the cost of the coal gasified," is obtained. It is also stated that " the gas is absolutely uniform in quality, and of higher calorific intensity than ordinary coal gas, giving a more brilliant light in the incandescent burner, and boiling a kettle more quickly than ordinary coal gas. It burns freely to complete combustion and gives off no smoke, soot, or obnoxious fumes when cooking. In the raw state it possesses the characteristic odour of coal gas, as required by the Board of Trade. 'Tully gas' is practically pure gas, the inertia not exceeding, at any time, 10 per cent."

As this plant consumes the whole of the combustible part of the coal or coke, there is no tar or residual products other than ash or clinker. An average analysis of the gas shows :—

CO_2 = 5·6 per cent.	O_2 = 0·6 per cent.
C_nH_n = 1·0 ,,	CO = 32·0 ,,
CH_4 = 8·51 ,,	H_2 = 48·64 ,,
N_2 = 3·65 ,,	

Charging Retorts.—The charging of horizontal or inclined retorts is attended with certain difficulties in connection with the even distribution of the coal over the entire base of the retort, by hand labour, especially when the retorts are double-ended and very long. Several kinds of apparatus have been designed to charge these retorts more efficiently and more economically ; one of the earliest and perhaps the best known of these mechanical charging machines is that designed by West, and from 1873 onwards he made a great many improvements in the method of charging retorts ; the chief difficulty was still the uniform distribution of the coal. Various forms of scoops, some running on wheels, others in the form of skips on wheels, were pushed into the retorts and their contents discharged.

In 1881 West applied power in the form of compressed air, or steam, or electricity, to this method of charging. He also invented a double-charging

scoop on his charging machine, which is very elaborate; the operator stands on a platform at the rear of the machine, and by the movement of certain levers, all within his reach, he can control all the operations of the machine. The machine is mounted on wheels and runs on rails; to move it along the bench of retorts he simply turns a lever to start a motor, which may be propelled by compressed air, steam, or electricity, and by the action of a second lever, the clutch is engaged with the bevel wheel gear, which is connected with one of the wheels carrying the machine on the rails. The hopper for coal and the charger can be either raised or lowered at will, by means of chains and pulleys, and the coal discharged into the retorts as desired.

A further improvement was made by West in forming the scoop in two sections, as shown in fig. 265, for the purpose of more evenly distributing the coal. The scoops were filled and pushed into the retort and made to revolve in opposite directions, as shown by the arrows, through a part of their circumference, and delivered the two halves of the charge into the retort on each side; the motion of the scoops was arrested by stops. The scoops are each made in two parts, *m* and *g*, which are fixed to the central shaft *a* and *d*. The arts *n*, forming the opposite sides of the scoops, are hinged to the parts *p* and *q*, and kept in their place by means of pawls *h*, engaging notches in the headstock of each scoop. The hinged portions fall in, leaving the way clear between the scoops for the coal to fall, when they are reversed.

A similar method of charging retorts by machinery was designed by I. Ruscoe (B.P., 1810-1889); it was used for charging horizontal retorts, and (B.P. 14,720, 1890) and (B.P. 8,479, 1891) for charging and discharging inclined retorts. Another apparatus designed by Messrs. Woodward & Crossley (B.P. 4,246, 1892) operates a charging scoop almost on similar lines to that above described, the machinery being operated by means of a gas engine.

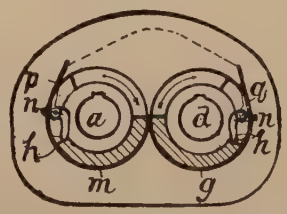


Fig. 265.—Double Scoop for "West" Retort Charging Apparatus.

A discharging machine designed by W. Foulis (B.P. 12,016, 1890) and a charging machine (B.P. 14,440, 1891), by Messrs. W. Arrol and W. Foulis, consisted of a hopper filled with coal, fitted with a slide in the bottom, and operated by means of a lever which causes the requisite amount of coal to be delivered on to a tray or scoop in front of the mouth of the retort. Two hydraulic rams then move a pusher forward, which pushes a portion of the charge into the further end of the single retort; the pusher is then withdrawn, and a second charge is pushed in, the operation of the rams being adjusted so that the stroke is diminished automatically as the charge fills the retort up to the required depth.

A quite different method of charging retorts was introduced by F. Grein (B.P. 16,750, 1892), a side elevation of the apparatus being shown in fig. 266; this machine, which is extremely simple, both in mechanism and in operation, consists of a hopper A mounted on a carriage designed either to run on rails on the ground or on overhead rails, D; an endless conveyer B is mounted at the bottom of the hopper containing the coal, which is delivered on to the conveyer, which is then pushed into the retort, C, the conveyer distributing the charge along the bottom of the retort on its backward movement. The foregoing methods all have the mechanism for charging by entering into the retort; another method, however, by which no mechanism enters into the retort was designed by De Browver (B.P. 23,212, 1901). The coal is projected

into the retort to the requisite distance as may be required by means of a large wheel, hollowed on the face, inside of which are inserted strips of leather or similar material. The wheel is driven by a belt over a pulley, actuated by an electric motor, the coal being discharged from the wheel into the retort as the belt and wheel leave each other. The whole apparatus is supported upon a vertical, adjustible frame suspended on trunnions, fitting loosely within the guide and chains attached to a winding machine winch, so that by this means the frame is capable of being tilted for directing the charge into the retort.

De Browver also designed a machine for discharging the coke from the retorts (B.P. 14,089, 1903), consisting of a ram operated by a chain, the links of which are pivoted together, and provided with teeth which form a flexible rack, operating the pushing ram, either backward or forward.

A great number of devices have been prepared for feeding gas retorts ; those enumerated above are only a selection. It is of importance in charging a retort to see that the coal is evenly distributed along the entire length of the bottom of the retort, and that it does not form mounds, that is, is not laid in heaps, because when heaps are formed these swell up with the heat during the period

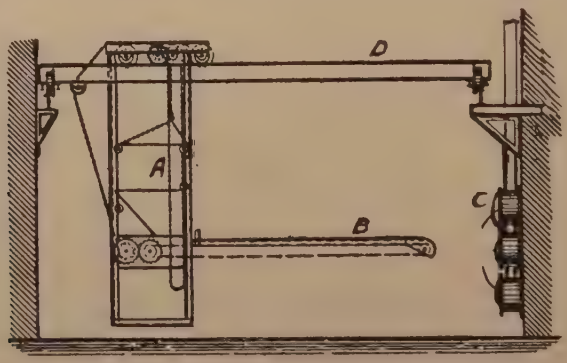


Fig. 266.—Apparatus for " Grein " Retort Charging.

of carbonisation, and may cause the entire periphery of the retort at this place to be filled up ; and as the gas has to find its way to the end of the retort to escape into the ascension pipe, these obstructions may give rise to irregularities in the making of gas owing to undue pressure in the retort.

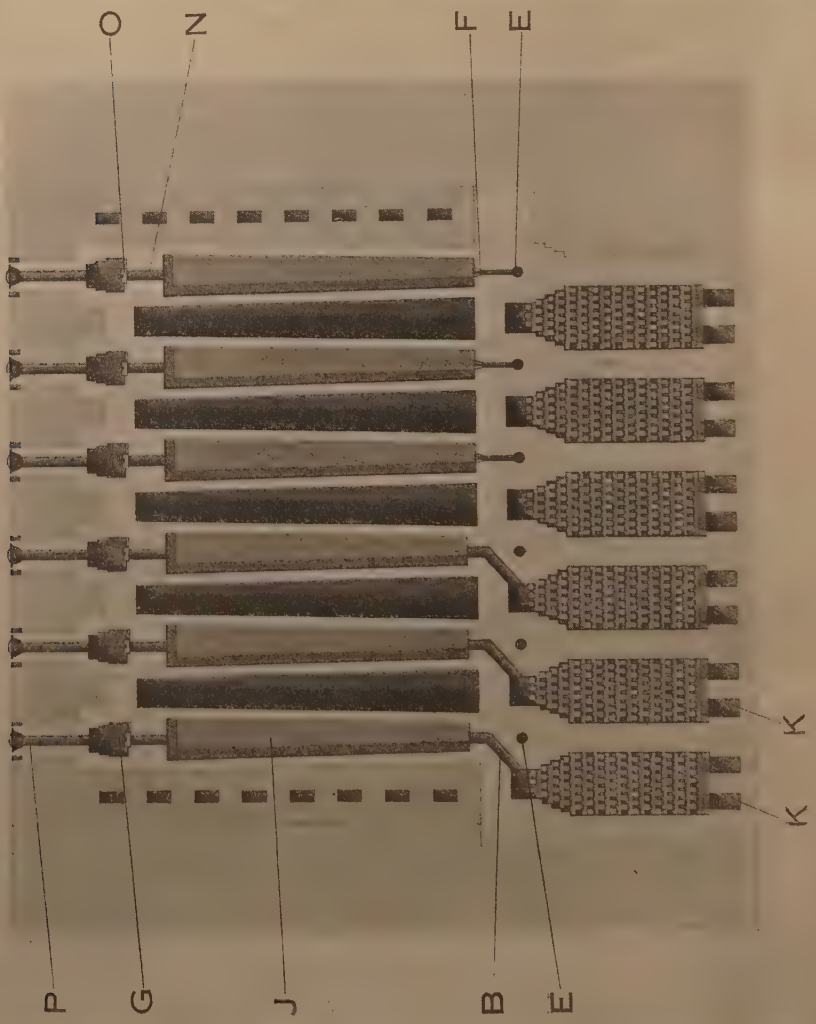
Some engineers state that the coal should be fed into the retorts and laid down loosely, and without pressing it ; but it matters little in the horizontal retort, with the shallow depth of the coal, whether it is loose or pressed, in fact, as coal is a bad conductor of heat, it would seem that the more it is pressed down the quicker it would be carbonised and part with its gas ; of course, different classes of coal require somewhat different treatment for successful carbonisation. Coal that is given to much swelling up should be laid in the retort in thinner layers than coal which does not swell up. Generally, coal is charged into the retorts loosely, except in the case of vertical retorts and long inclined retorts, where the coal must, under certain conditions, be very compact ; but in these cases the make of gas is materially increased, as Padfield proved at the Exeter Gas Works, when vertical retorts were installed, from which he obtained as much as 13,000 cubic feet of gas of 14½ candle-power from one ton of

Somerset coal, which, when carbonised in horizontal retorts, only gave a yield of 10,500 cubic feet of gas.*

Chamber Carbonisation.—As pointed out earlier in this chapter, when dealing with vertical retorts, and their recent construction, the tendency in the modern production of town gas is towards the system of carbonisation carried on in the manufacture of by-product coke, the object being one of economical working, combined with maximum make of gas from a given quantity of coal, and the principles underlying the proposal to carbonise coal in more bulky quantities has behind it the saving of labour in the working of the plant, and this has been proved in the recent plants constructed for this purpose. While candle power gas was demanded, the retort system predominated, one of the reasons being the difficulty experienced in producing gas of an equivalent value in the chamber to that produced in the retort. The retort method of carbonising for gas manufacture ensures more thoroughly the absence of air during the period of carbonisation, whereas in the chamber this is not so easy to accomplish to the same extent. In the coke oven a certain amount of atmospheric air finds admittance through the doors, which are seldom, if ever, absolutely air-tight; when a retort is worked with a partial vacuum, the door is generally air- and gas-tight, but the door of the oven is otherwise, especially after the luting has become desiccated and shrunk. Now that this subject has been seriously considered by several gas companies for the manufacture of gas in chambers which resemble coke ovens in most of their constructional details, provision is made to secure the doors in a more air-tight way than obtains in the general coke oven practice. One of the first installations for the manufacture of gas for town supply by this method was at the Corporation Gas Works in Vienna; it was based upon the principle devised by Messrs. Koppers Coke Oven and By-Product Company. Fig. 268 shows a section through the horizontal chamber oven constructed by this firm for the Birmingham Corporation Gas Works. On the left of the chamber is the coal charging and coke quenching machine, and on the right is the coke-pushing and coal levelling machine. The chamber oven is constructed by practically the same method as that used for coke oven construction. Fig. 267 is a cross-section through the chamber and through the heating flues. In working this chamber oven, all the gas made is for delivery to the town mains, none being used to heat the chambers. The latter are heated by means of producer gas, made specially, and conducted to the ovens by pipes. The ovens are constructed so that the waste heat from the combustion of this producer gas on the heating flues is carried away through a set of regenerators in the base of the ovens, in which both the producer gas and the air for combustion are pre-heated; when using producer gas this pre-heating is necessary if a standard high temperature is to be maintained in the heating flues. Referring to fig. 268 as a combination oven, it will be observed that the regenerators beneath each chamber are divided into two compartments by a division-wall, and are connected to the combustion flues by channels. The regenerators are arranged for pre-heating the air and gas alternately, that is—one regenerator is for air, the next regenerator is for gas, then air, then gas, and so on throughout the whole length of the battery of chamber ovens. Both the gas and air, after passing through the chequer brickwork in the regenerator are heated to a temperature of about 1,100° C., and as they issue from their respective and adjoining regenerators by the channels, B, fig. 267, they are ignited immediately, and burn up the vertical heating flues, J. The system of working is to heat one half of the heating flues by this means in the oven walls

* Butterfield, "Gas Manufacturing," p. 115.

while the products of combustion are gathered into the horizontal flue, G, and pass down the other corresponding half of the heating flues in the chamber walls, then through the regenerator into the chimney flue. This method of procedure in heating the chamber oven is almost identical with that practised in the coke oven. The reversal of the heating of the one half of the flues is done



about every 30 minutes, with the discharge of the products of combustion down the other half of the flues, and so on alternately. The regulation of the temperature is maintained also by the same arrangement of inspection apertures, and damper valves. The gas is regulated by means of cocks on the service pipes. The chambers are charged by means of a machine which runs

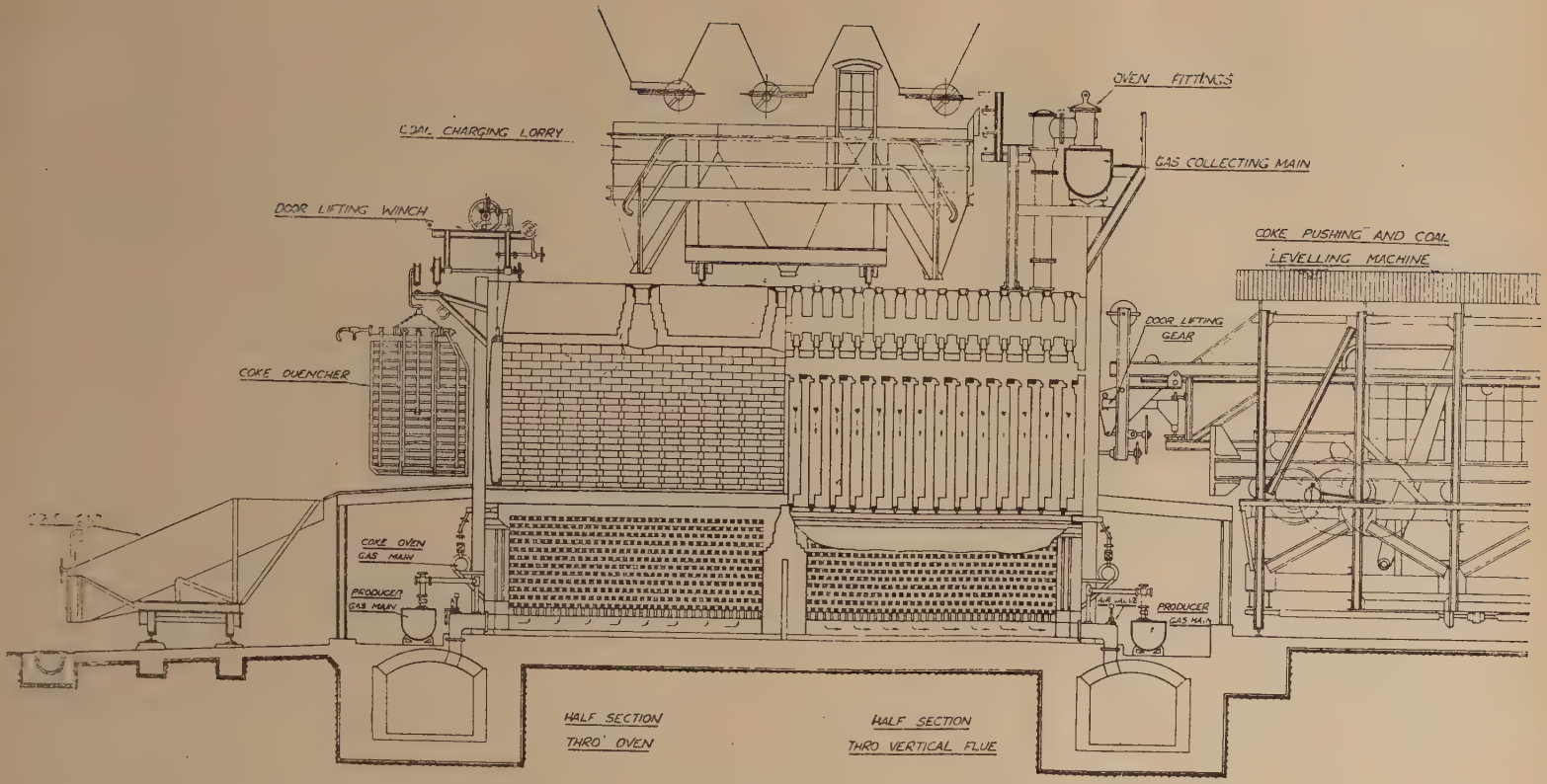


Fig. 268.—Section through " Koppers " Combination Oven.

on the top of the setting; this machine has three hoppers, charging into corresponding openings in the roof of each chamber; the coal is levelled by another machine which travels alongside the bench of chamber ovens, and also operates with a ram to push the coke out into a quenching machine after the period of carbonisation is completed. Fig. 269 shows a battery of

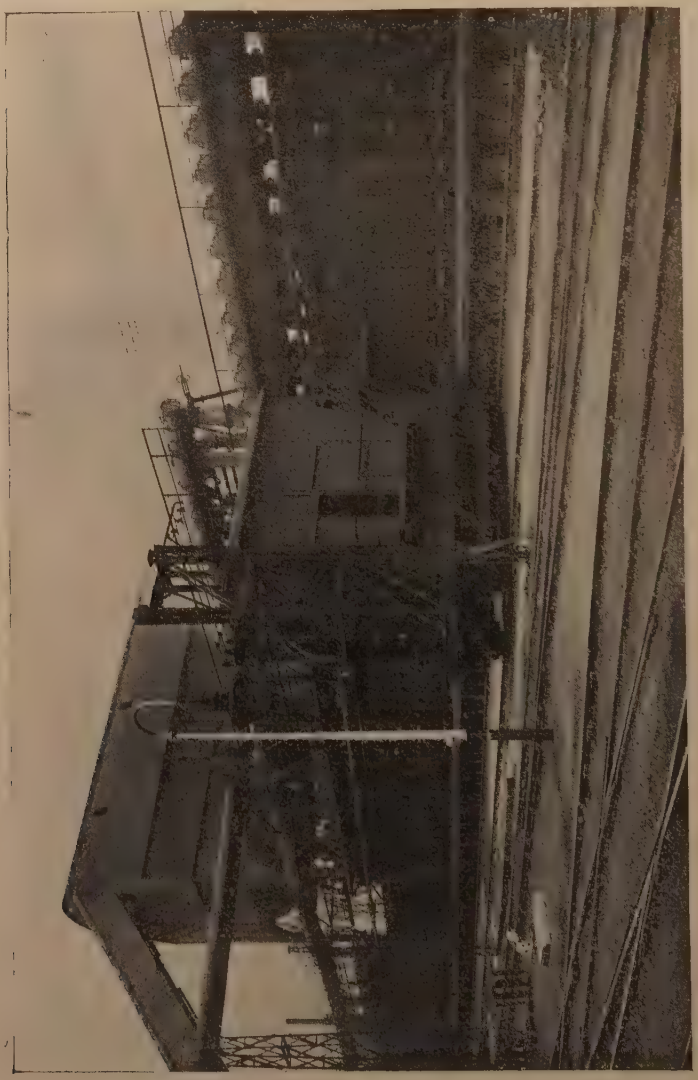


Fig. 269.—Battery of 66 "Koppers" Chamber Ovens at the Saltley Gas Works, Birmingham. View of Pushing Engine Side.

chamber ovens at Birmingham Gas Works, and fig. 270 is the coke discharging side of these ovens. The charging machine is to be seen on the top of the ovens on the left in fig. 271, which shows a vertical section through chambers and heating flues. Fig. 272 is a view of a battery of 72 of these ovens at the Vienna Gas Works, making over 7,000,000 cubic feet of gas per day.

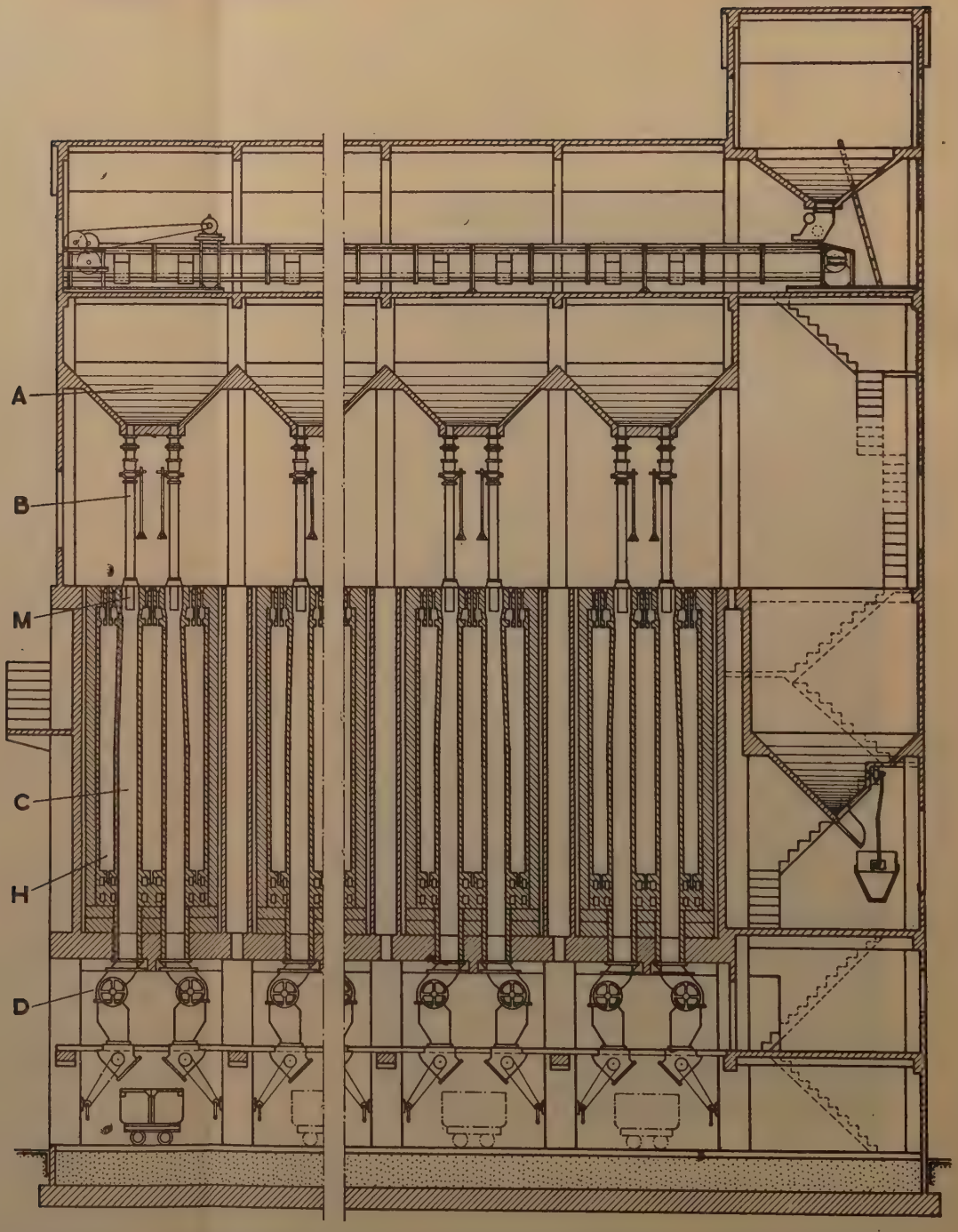


Fig. 271.—Sectional Elevation through Ovens and Heating Flues (Saltley Gas Works, Birmingham).

Figs. 271 and 273 represent a continuous Vertical Chamber Oven. The coal is delivered into a hopper, A, over the ovens, and passes by gravity continuously through a charging chamber, B, into the oven chamber, C. The ovens are heated by means of the flues, H, the gas being supplied by the producer, E, through the pipe F, and heated in the regenerator, G. The air

Fig. 270.—Battery of 66 "Koppers" Chamber Ovens at the Saltley Gas Works, Birmingham. View of Coke Discharge Side.

for combustion enters the adjoining regenerator. The products of combustion travel up the full length of the heating flues and at the level of the top of the oven chamber take their exit through channels into the second pair of regenerators, I. After a period of time, about half-an-hour, the reversal is made, and combustion takes place in the heating flues from the top down-

wards. The waste heat gases are then conducted to the regenerators at the base, and on to the chimney by the flues, K. The oven chamber is from 26 to 30 feet in height, from 8 to 10 feet broad, and from 12 to 13 inches wide, and is constructed with special silica bricks.

In connection with the whole of the installations on the Continent by Messrs.

Fig. 272.—Battery of 72 "Koppers" Chamber Ovens, having a capacity of 7,400,000 cubic feet of gas per day, at the Leopoldau Gas Works, Vienna. View of Coke Discharge Side.

Koppers for the carbonisation of coal for the production of gas in chamber ovens, the gas for heating the chambers is supplied from Kerpely Gas Producers, and it is stated that the principal features of this producer are as follows :—

"The revolving mechanical grate and water-cooled jacket ; this latter

prevents the adhesion of clinker to the sides of the producer; the automatic ash discharger, which considerably reduces the labour costs; the duplex air and

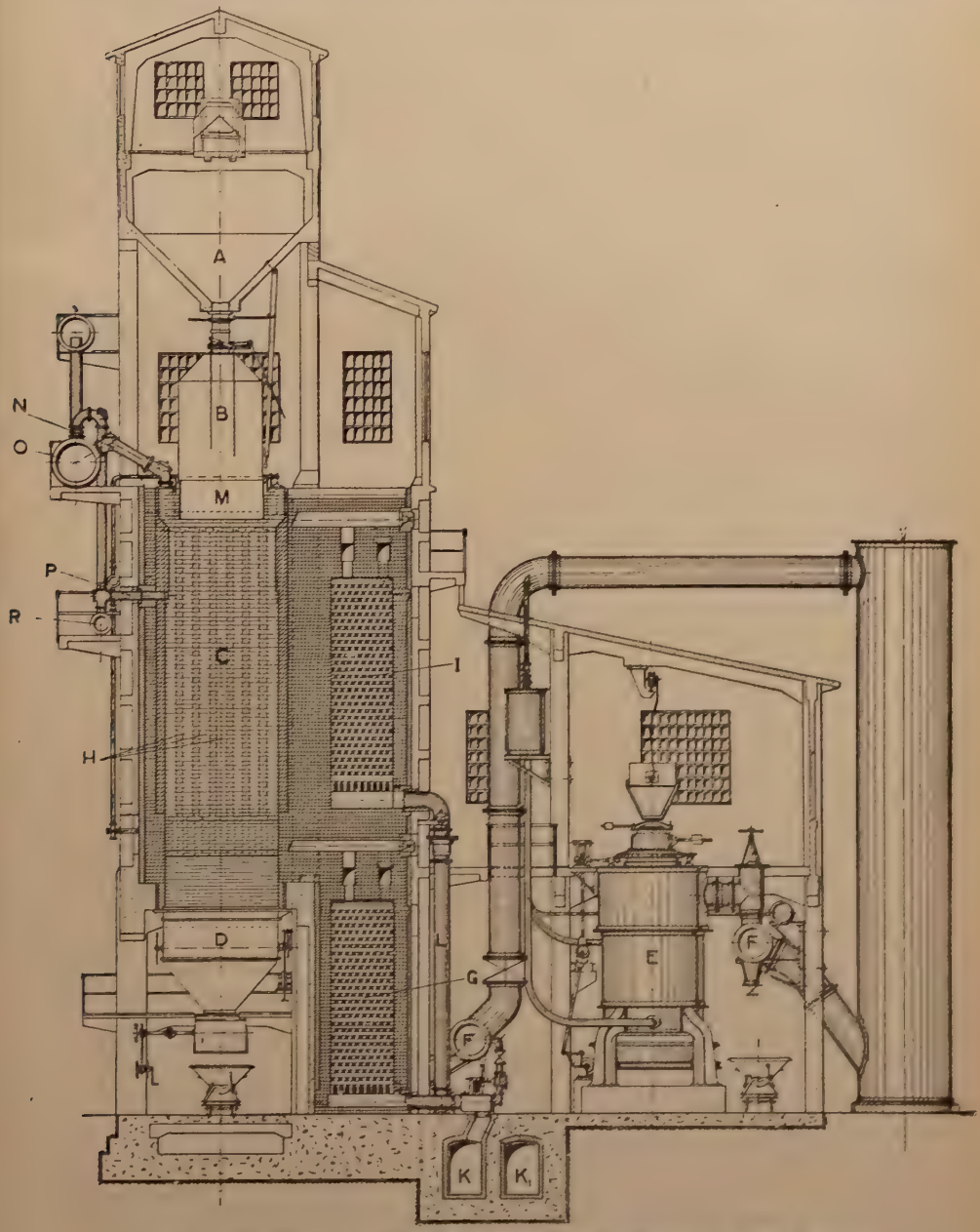


Fig. 273.—Cross-sectional Elevation showing relative position of Oven Chamber, Regenerators, and Gas Producer.

steam supply which allows the regulation of gasification, and secures uniform combustion over the whole grate area. Owing to the loosening effect of the grate, the blast is uniformly distributed, and consequently the composition of the gas made varies very little indeed. The following is an analysis of an average sample of the producer gas made in this producer :—

Carbon monoxide, CO,	29·84 per cent.
Hydrogen, H_2,	9·12 „
Carbon dioxide, CO_2,	2·78 „
Methane, CH_4,	0·8 „

The calorific value is about 137 British Thermal Units per cubic foot."

The actual results with chamber carbonisation for town gas supply by the Koppers system, as carried out in the plant at the Vienna Gas Works over a period of six days, were as follows :—

Quantity of coal charged,	1,169·76 tons.
„ „ „ per oven per day,	10·83 tons.
Time of carbonisation,	23 hours 35 mins.
Production of gas per ton of coal, corrected to N.T.P. (coal containing moisture and 8 per cent ash),	11,833 cubic feet.
Calorific value (average) per cubic foot,	612 B.T.U. gross.

Analysis of Gas :—

	Per cent.
Carbon dioxide, CO_2,	2·60
Hydrocarbons, C_nH_m,	2·93
Oxygen, O_2,	0·37
Carbon monoxide, CO,	9·17
Hydrogen, H_2,	53·27
Methane, CH_4,	29·20
Nitrogen, N_2,	3·48

It is also stated that the yield of ammonia from the same coal by this plant is greater than with other plants, while the tar is superior to ordinary retort tar, being more fluid and containing less free carbon (usually not more than 3 to 5 per cent.).

With a recent plant erected at the Budapest Gas Works, by the same firm, the Koppers direct process for the recovery of ammonia was established, and it is stated to be the first instance of a large gas works adopting the direct ammonia recovery process.

Fig. 273 is a vertical section through the ovens and gas producer at the above works, showing the relative positions of the ovens, the regenerators, and the gas producer.

CHAPTER XIII.

LOW TEMPERATURE CARBONISATION.

It is now about twenty years since the low temperature process was put forward as a commercial undertaking, and during this time many inventors and experimenters have been hard at work devising means to ensure success to the conducting the carbonisation of coal at a temperature not exceeding 600° C. That this problem is not a simple one is now well known, since the company that originally undertook to produce commercial results by the process they proposed in 1907 have encountered enormous difficulties, and, although with a nominal capital of £2,000,000, they were unsuccessful in producing any commercial results. Others have stepped into their place, and claim to have succeeded in perfecting a plant for the manufacture of the articles aimed at upon a commercial scale.

There are several processes now claiming to have solved the problem, but it will be sufficient here to give a description of a few of the most prominent.

The Low Temperature Carbonisation Company, Limited, is the successor of the "British Coalite Company, Limited," which was founded in 1907, and had works at Wednesfield, where they were making coalite according to the patented process of Mr. T. Parker (B.P. 14,365, 1906).

There seems to have been a lack of knowledge regarding the practical carbonisation of coal, especially coal of a bituminous or coking quality, shown by the fundamental errors displayed in the patent specifications describing Parker's invention; during three years he applied for nine patents, all of which were not practical in the carrying out of low temperature carbonisation below 600° C. His last patent, No. 3,003, A.D. 1909, for iron retorts, states that certain provisions are made for "each retort being provided with a slit at the bottom communicating with adjacent retorts, so that in the event of any retort becoming choked at its upper part, the gas may escape through the adjacent retort." From this it will be gathered that the difficulty encountered at the outset, and all along, in the use of narrow retorts, was the coal agglomerating and sticking to the sides of the retort, so that an impassable barrier was created, through which the gas produced in the lower regions of the retort could not escape; but this outlet at the bottom was not a remedy, since the coal, in fine division, together with tarry matter, filled up these outlets. Higher temperatures were then tried, which released the carbonised coal from the walls of the retort, but the cast iron retorts could not stand this treatment for long, and fireclay retorts were then substituted. When the author was in Scotland, at the works of the Glenboig Fireclay Co., he saw a lot of retorts made for this process, and at once communicated with the company's manager and pointed out the fallacy of using huge retorts, which were about 5 to 6 feet long by about 3 feet broad, and about 4 inches wide inside; some years previously this retort had been tried for another purpose by the author, and from his experience he was convinced that it could not possibly stand the making of coke, the fact being that large retorts of fireclay, when heated up, crack, and those made of such broad and flat dimensions having no support, practically collapse, and even when supported by brickwork the loss of gas through the cracks into the heating

flues raises the temperature of carbonisation very much above 600° C., so that ordinary gas works' coke is produced on the sides, with partially coked or low temperature coke in the centre.

Then came the difficulty of discharging these narrow retorts; when cracked and distorted the coke had to be forced out; ultimately they were abandoned.

The discharging of retorts after low temperature carbonisation is difficult, owing to the tarry matter not being sufficiently carbonised and the coke produced not having developed the necessary contraction to enable it to fall away from the walls of the retort; none of these difficulties occur in high temperature practice, because the tarry matters are well carbonised and the coke is shrunk. In fact, as pointed out in another part of this work, the coke, by reason of its shrinkage, leaves not only a large space between it and the walls of the oven, but a corresponding space is developed in the centre of the coke charge.

In the author's own researches on low temperature carbonisation, in connection with the Briquetting process, described in another chapter, he found that, in using iron moulds, the coal, when coked at a temperature between 450° and 550° C., is not always easily freed from the iron, but when a temperature of 600° to 700° is reached there is no trouble. By exposing the mould to a temperature of 700° C. for a short time, then reducing the temperature to 550° or 500° C., the coke clears easily; the reason of this is, that the high primary temperature cokes the outside and forms a hard skin, and the tarry matter is completely carbonised locally, so that there is no adherence subsequently to the iron.

Low Temperature Carbonisation Company's Process.—The Low Temperature Company claim to have overcome all the difficulties in the manufacture of *coalite*, by means of a new retort.

The following is a description of the new retort and process, kindly given to the author by the manager of the Low Temperature Carbonisation Co.:—The retorts are constructed of fireclay and formed with grooved and tongued bricks; each retort is 9 feet 6 inches deep, 11 inches wide, 7 feet 3 inches long at the top, and 7 feet 6 inches long at the bottom; the retorts are arranged at a central distance from each other of 21 inches. The interiors of the retorts are formed with semi-circular ends. The retorts are heated by means of gas brought to them by supply pipes, with branches to each flue. The heating flues are horizontal, and an arrangement of eight superimposed flues is used, heated by four branch gas pipes on each side of the retort setting. The method of heating being arranged *per descensum*, the gas introduced into the top heating flue is consumed by air, heated in the brickwork at the sides of the setting; the products of combustion in the top heating flue flow down through a port hole, actuated by a damper. The gas and heated air in the flue underneath mixes with the products of combustion from the upper flue, and so on, till the bottom flue is reached, when the products of combustion from all the flues are gathered into the waste heat flue. The incoming air for combustion of the gas is made to travel in flues alongside the waste heat flues, and is thus recuperated. This method of burning the gas and heated air and products of combustion together in the lower flues seems to be a strange one; there must be waste in the lower flues, since combustion must be retarded, and in certain conditions of the furnace, the combustion cannot be complete, owing to the presence of the accumulation of carbonic acid gas from the products of combustion of the upper flues. The system is not new, as it was practised many years ago for the purpose of reducing the temperature locally where the products of the previous combustion were admitted. The gas used to heat the retorts is that

made during the carbonisation of the coal in the retorts; it is extracted from the retorts, washed, and returned to the setting by means of the gas

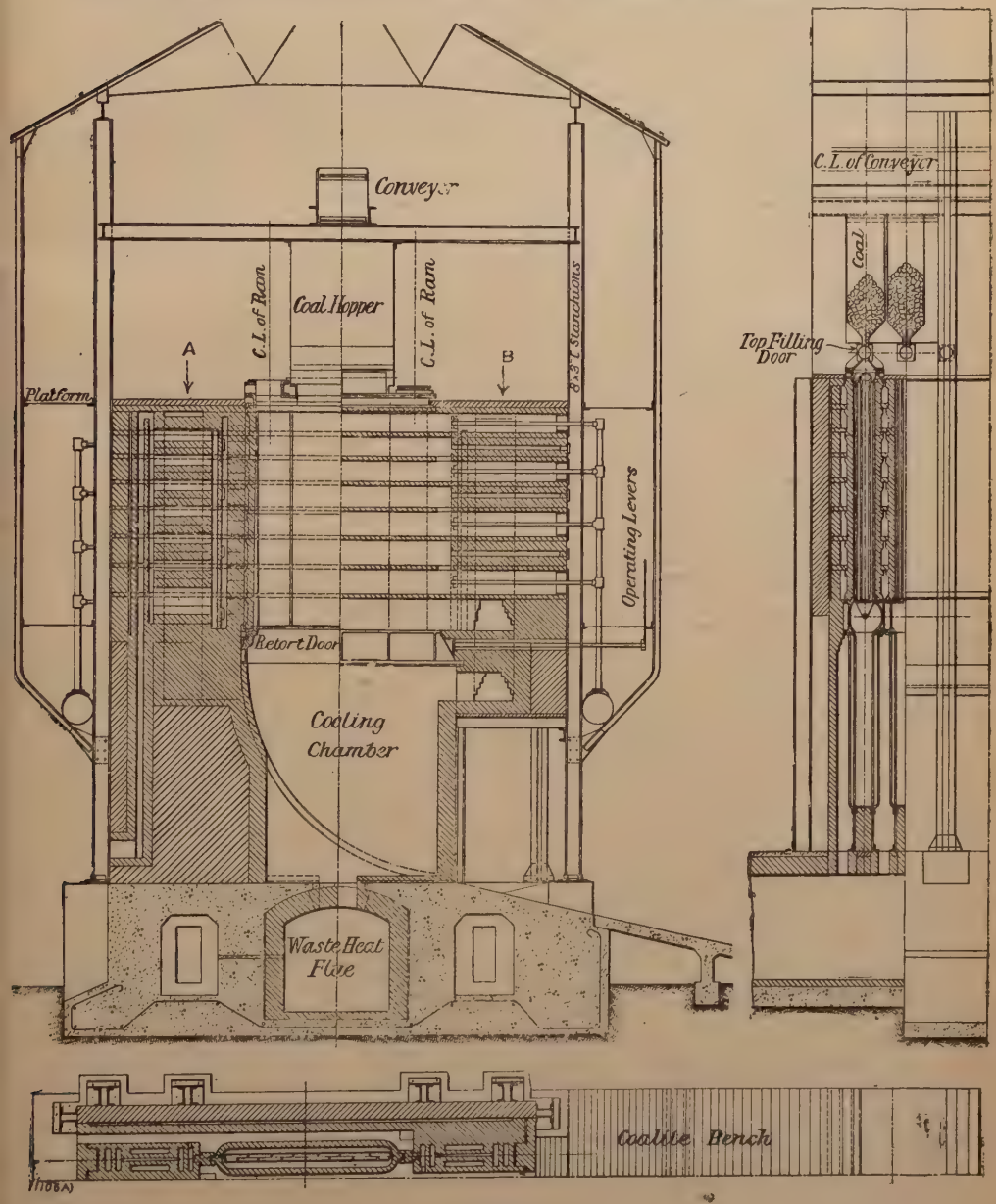


Fig. 274.

mains shown in fig. 274. It is now proposed to use a Mond gas producer for this purpose, and to use the gas from the retorts for other purposes.

The retorts are constructed in the interior of the setting; the recuperation for the air and the exit for the products of combustion are arranged at each end of the retorts. In the interior of the retorts are placed a pair of collapsible plates, shown in vertical section in fig. 275. These plates are formed of cast manganese iron and occupy the central portion of the space between the walls of the retort; the charge of coal lies between the outside of these plates and the walls of the retort, which averages about 3½ inches. The plates are perforated with holes, and are generally made in three sections, and when bolted together form one plate 9 feet 6 inches long by 6 feet 5 inches wide. When the coal is charged into the retort, the expanded plates are on the same level at the top, as shown in fig. 275, but when the coked charge is finished, and the plates are collapsed to release the charge, they are as represented in fig. 276. This arrangement is very ingenious. In order to keep the plates at their proper parallel distance apart, there are flange abutments provided, which prevent the pressure of the coal forcing the plates together, the adjustment of their collapsible distance being governed by means of connecting links, shown at the bottom of

Fig. 275.

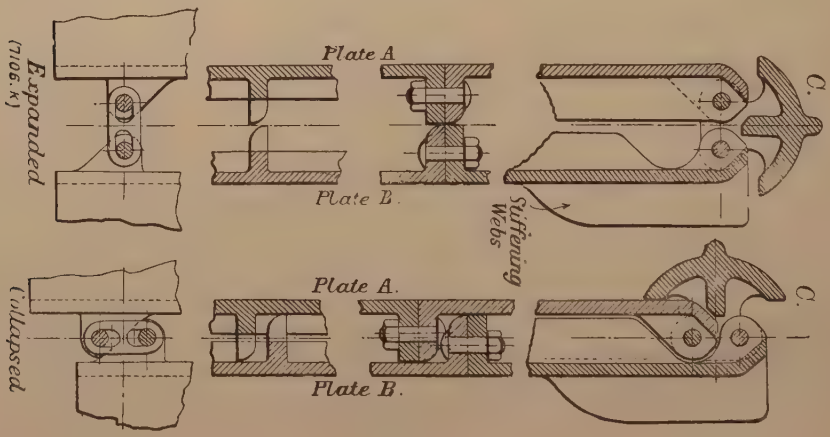


Fig. 276.

figs. 275 and 276. The mechanism for moving the plates is shown at the top of figs. 275 and 276; this is performed by the bridge piece, actuated by means of a ratchet lever, which moves the plates on the pins, one up and the other down, when the retort is discharged. The plates, when open to receive the charge of coal, are 5 inches apart, but when they are collapsed, they are only 3 inches apart, so that the charge has perfect freedom to fall out when these plates are so moved, and the door at the bottom of the retort is opened.

During the process of carbonisation the plates are moved slightly together in order to relieve the pressure of the swelling coal as it carbonises, so that the coke made will not be too close or hard, at the same time releasing the apertures in the collapsible plates, so that the gas given off may have a free exit into the space in the centre of the plates when it passes upwards to the gas off-take; the operation is performed thus for the purpose of preserving the gas from decomposition, the interior of the two plates being comparatively cool. The gas off-take is shown in fig. 278.

When the process of carbonisation is complete the plates are collapsed, and

the door at the bottom of the retort is opened (fig. 277), the charge falling into the cooling chamber, constructed below the retorts. The top of this chamber is shown in the vertical section through the retort on the left hand of the central line, and in the section through the heating flues on the right of the central line, with the cooling chamber beneath.

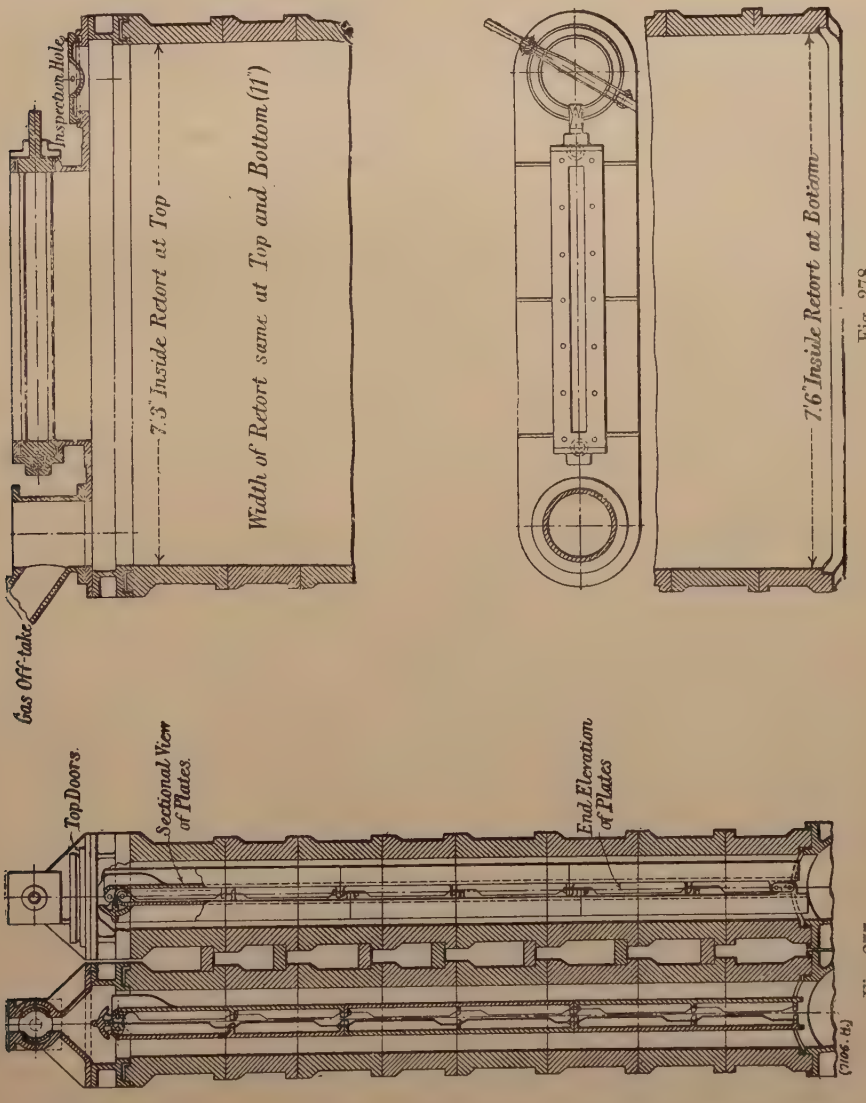


Fig. 278.

Fig. 277.

The cooling chamber is constructed as shown in fig. 279, and is made of sheet steel; the two water-jacketted sides are connected to a curved steel back. There are thin vertical plates fixed in the central part of these jackets, dividing each jacket into two compartments.

The water that is contained in the inside compartment will be heated by the

hot charge when it is lowered from the retort above; this water will rise and flow over into the cool compartment on the other side of the jacket, and there will be consequently a circulation of cool water in the jackets; it is stated that by this means steam is raised in the jackets, and it is proposed to "fractionate the tar oils as soon as this can be undertaken at the works" with the steam thus generated. The charge is left in this cooler for two hours, when it is

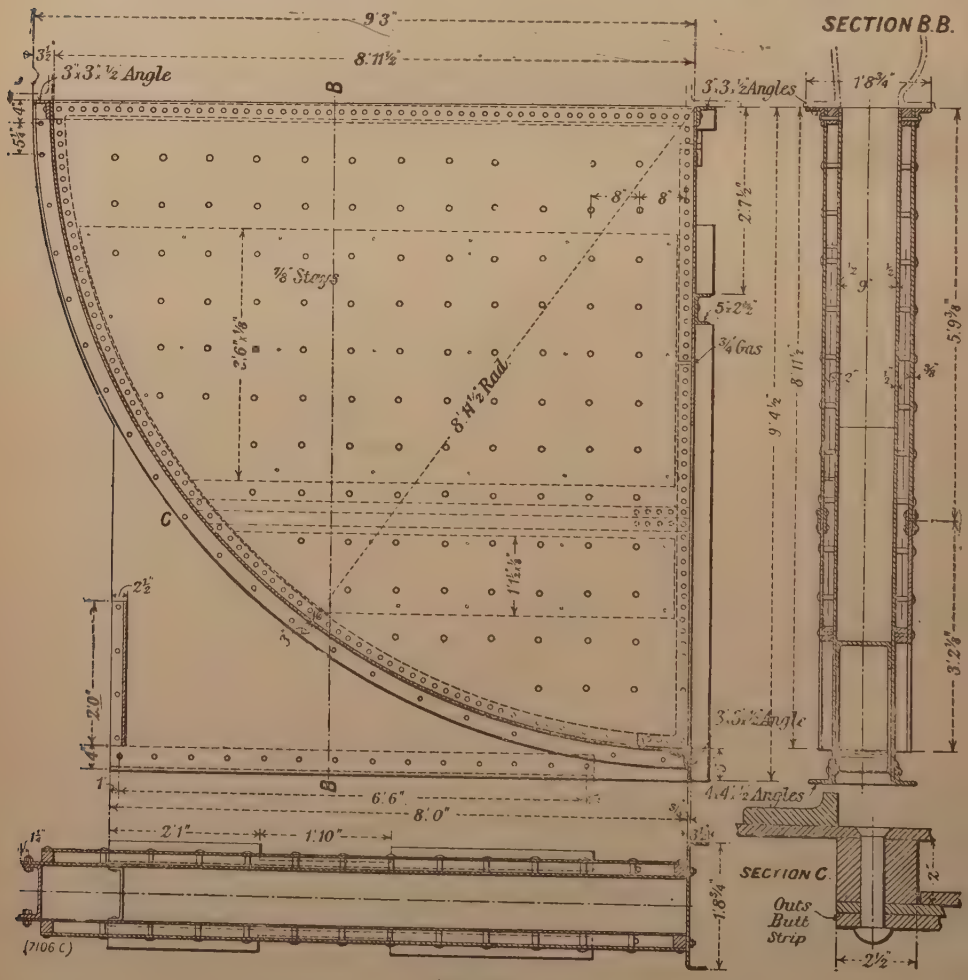


Fig. 279.

sufficiently cooled to be withdrawn, previous to the dropping of another charge from the retort.

It is stated that practically all the gas produced in this process is used for the purpose of heating the retorts; this is rich gas, and would be suitable for the purpose of heating the furnace or setting on the plans adopted, but it is very questionable if Mond Producer gas could be made to serve the same purpose

in this setting, owing to the fact that such gas contains a large quantity of CO_2, and if the same method is adopted of carrying the products of combustion through all the heating flues using Mond Producer gas, it is doubtful if the flues at the lower part would be heated at all; the great accumulation of CO_2 would depreciate the combustion in the lower flues to such an extent as to almost, if not totally, extinguish the flame; at any rate, the loss of unconsumed gas would be very great without some alteration in arrangements.

The enormous amount of brickwork in front and at the rear of this setting may be necessary to keep up the temperature; but such masses are expensive in first cost, and in maintenance, by reason of the expansion and contraction, and the difficulty of binding such a wide range of setting with retorts of such large breadth and narrow capacity; this was made clear in another chapter dealing with vertical coking chambers.

The output from such a setting is, by low temperature carbonisation, comparatively small; the labour costs and general overhead expenses, proportional; it follows, therefore, that account must be taken of the enormous amount of plant that would be required for a given output, compared with the high temperature process; but if the *coalite* and other by-products obtained find a market at prices compatible with these inevitable difficulties in their production—well and good; but it is the opinion of the author that a combination of both low and high temperature carbonisation would be much sounder, especially with regard to the construction of the settings. This could be easily arranged, using a certain class of high temperature coke oven, in which the *coalite* and its by-products could be produced in a much less costly setting, and where the cost for heating the retorts would be nil, and all the rich gas produced would be saved.

The problem of economic carbonisation for the manufacture of *coalite* and the production of "oil," is of the utmost importance, if these articles are to compete in the open market. In common with the production of oil the following is stated by an exponent of the above process in a pamphlet entitled "Coal and its By-products,"* viz.:—"To carbonise the coal in closed retorts at as low a temperature as possible (about 1,000° F.) so as to retain part of the volatile matter in the residual fuel (*coalite*), and to decompose the remainder only to the stage of obtaining the maximum yield of liquid by-products, with the minimum amount of gas. By this method the ordinary *coalite* process gives, for example, from 1 ton of average coal (25-30 per cent. volatile matter), 14 cwts. of *coalite*, 3 gallons of motor spirit, 20 gallons of oil, 15 lbs. of sulphate of ammonia, and an amount of rich gas (700 B.T.U. per cubic foot), which very roughly amounts to 3,000-5,000 cubic feet. The residual fuel, *coalite*, retains about 10 per cent. of volatile matter, and consequently, while being absolutely smokeless, is easily ignited and burns cheerfully without smell.

"Undoubtedly the most important aspect of low temperature carbonisation is the production of oil from coal. In the first place, there has been much difference of opinion as to the amount of oil produced, but a yield of 18-20 gallons per ton for average coal seems to be now beyond dispute, and the old contention by opponents of low temperature carbonisation that the yield is little more than that with high temperature carbonisation, say 12-14 gallons, is to-day no longer regarded seriously by anyone.

"We now come to the knotty point as to what is to be taken as the real value of these oils in calculating out the balance-sheet of the process. It is always very difficult to put a proper value on any new process the products

* By the *Financial Times* technical expert.

of which have not yet entered extensively into the open market, and in the case of low temperature carbonisation it is more than usually difficult, because the price of the competitive product, petroleum oil, is liable to fluctuate violently. Thus some figures have been taken as low as 4d. per gallon, and even the Fuel Research Board have calculated the figure as only 5d.; in the opinion of the writer this is an entirely inadequate figure. It is, of course, very necessary when calculating the value of any new process to keep well on the under side, but there seems to be little real object, at any rate from the point of view of an impartial consideration of the case, in regarding low temperature oils produced in our country as only equal in value to crude petroleum in a time of slump.

"Another very remarkable statement contained in the report is that, as a result of the latest researches now proceeding, up to 10 gallons per ton of motor spirit have been obtained." But this yield of motor spirit cannot have been

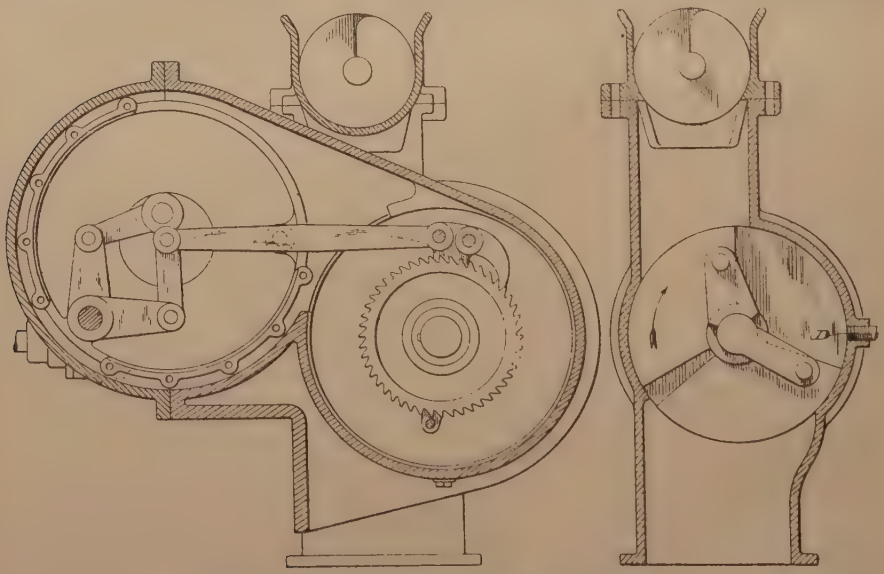


Fig. 280.—Mechanism for "Lamplough" Retort.

obtained without a secondary process in addition to that of low temperature carbonisation.

Upon the consideration above stated, that the paramount object of the low temperature system is not the production of *coalite* only, but of oil, the next process to be examined is that of Frederick Lamplough, in which oil is the primary object.

Lamplough Low Temperature Process.—This process was invented by Frederick Lamplough in 1914, and was patented (B.P. 15,892, B.P. 108,343 and 124,294, A.D. 1914). In the preamble of his specification he states:—"This invention is for improvements in or relating to the low temperature distillation of coal, and apparatus therefor, the objects being to subject the coal to partial distillation in such a way that it does not reach the coking stage, thus removing only the light oils and hydrocarbons, aud leaving a smokeless fuel. It is well known that the ordinary methods of retorting coal for the production

of gas and coke are not effective for the production of oil, or ammonia, from the coal. This is partly due to the conditions under which the distillation takes place, and partly to the fact that as coke forms on the inside of the retort tube, it insulates the coal in such a manner that excessive heat is required to reach the centre of the retort; thereby a considerable decomposition of the oil takes place. As in previous process the coal is passed continuously throughout the whole apparatus, and a measuring hopper of the type provided with an air-lock is used." The coal is introduced to the apparatus by means of the "measuring hopper," which delivers any definite quantity of coal without allowing the escape of gas or any leakage of atmospheric air into the apparatus. The amount of coal is regulated by means of a "speed gear," shown in vertical section in fig. 280. The apparatus consists of a number of retorts in series, fitted internally with worm conveyers; the coal, after being subjected to partial distillation, is discharged into a receptacle from which it is taken and pressed into blocks while still hot.

The apparatus is represented in longitudinal section in fig. 282, and in end view with section through the discharge apparatus in fig. 281. The coal is fed into the measuring hopper by a worm working in a trough above. The hopper has two central concentric shafts which pass through the hopper into the operating gear, as shown in fig. 280. One of these shafts has fitted on to it two segmental blocks, which extend its whole length, and each of which describes circumferentially an arc of 120°. These blocks rotate at varying speeds in such a way that the space between them comes below the inlet from the supply trough above, so as to take up a quantity of coal, and to discharge it below into the carbonising apparatus; no gas is thus allowed to escape; a steam pipe is provided in the side of the hopper for the purpose of forming a plus pressure inside the hopper to exclude the air more effectively, the steam passing into the apparatus along with the coal; the feed is regulated by means of a double arm, bell-crank lever operating the pawl on the ratchet wheel, shown in fig. 280. The retorts are arranged above each other within the brickwork setting in a horizontal manner, each retort being provided internally with a worm conveyer for the purpose of conveying the coal through each retort in succession—that is, it is passed through the top retort, and then through the one below, until it reaches the bottom, and is ultimately discharged out of the apparatus by the worm conveyer at the bottom during the passage of the coal through these retorts, which are heated in the setting to a temperature of 400°-600° C., according to the nature of the coal operated upon. A train of toothed gearing wheels fixed

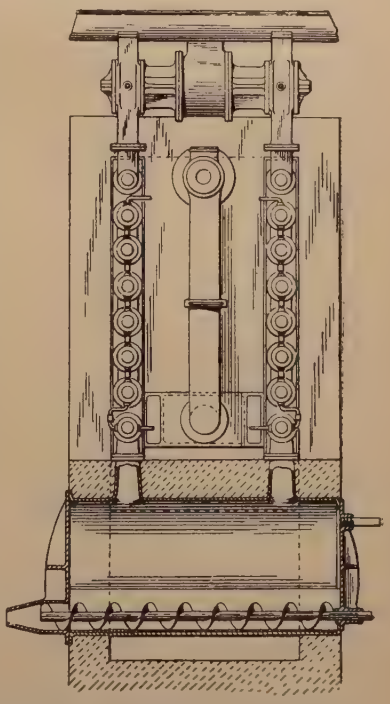


Fig. 281.—Elevation of "Lamplough" Retorts.

on the end of each worm conveyer outside the retorts keeps the coal on a forward and downward movement. An outlet in the discharging cylinders conveys the vapours away to the scrubbers and condensers. The steam, it is stated, operates for the production of ammonia, and for conveying the vapours away from the hot zone in the retorts more rapidly, and preserving the rich hydrocarbons from decomposition.

A further process by the same inventor in conjunction with " Oil Extractors, Limited " (B.P. 108,343, A.D. 1916), proposed to conduct the entire operation by means of superheated steam, preferably at low pressure, which is passed through the coal in an apparatus which consists of a battery of vertical retorts, with two parallel main pipes extending along the top and bottom of the retorts respectively.

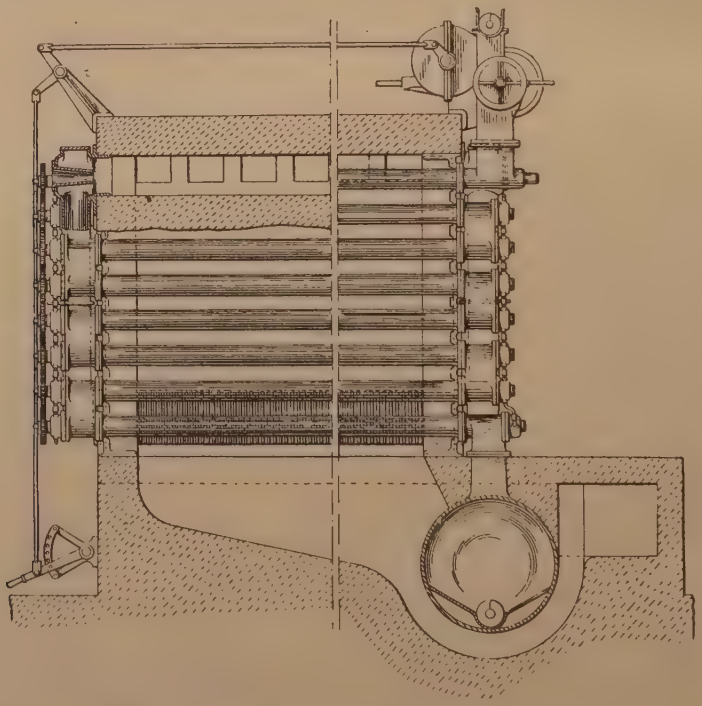


Fig. 282.—Section through " Lamplough " Retorts.

Superheated steam is passed into one of the lower main pipes, while the other pipe adjacent to it is used as a by-pass feed; the latter is connected by a rising pipe with one of the main pipes at the top of the retorts. On the upper part of each retort, fig. 283, is a hopper, under one side of which is formed an off-take, through which the effluent discharges into a chamber under the control of a two-way valve, so that it may be passed direct into the gas main, or may be by-passed more or less into the by-pass tube.

The battery of vertical retorts, *A*, is shown in vertical section in fig. 283. The parallel gas mains are shown extending along the bottom of the battery, and another pair of parallel gas mains is shown on the top of the battery. The main which has the charge of superheated steam has branches connecting each

retort respectively, which are under the complete control of a set of "mushroom valves," *L* and *M*, at the top, while another set, *T* and *H*, are at the bottom. These valves are arranged co-axially with one another, the stem of one valve being made hollow to allow the stem of the other to pass through it. The two stems pass through a stuffing box arranged above the branch pipe on each retort. Each retort is furnished with a feed hopper at its upper extremity, and with a discharge door at its lower end.

The superheated steam for the heating of the coal in the battery of retorts is provided by means of a superheater, *M*, fig. 283, which it is purposed to feed by exhaust steam from "steam engines, radiators, etc." The superheater is

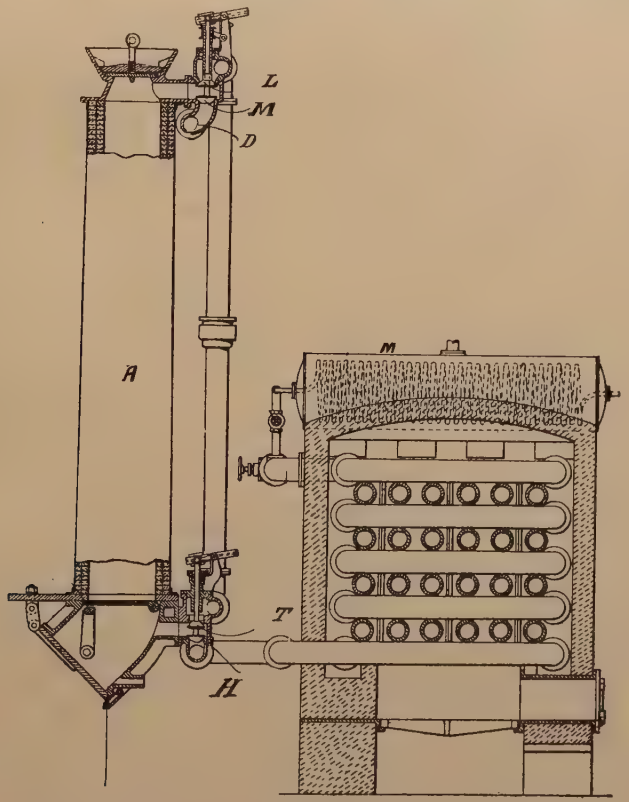


Fig. 283.—Section of "Lamplough" Retort and Superheater.

furnished with an evaporator, in the form of a cylinder built into the roof of the setting, accompanying the superheater, as shown on the right of fig. 283. This cylinder is connected with a "donkey-boiler" or some other source of live steam, and is furnished with an internal coil pipe, connected to a water supply at one end, and at the other end to the inlet to the superheater; this latter cylinder is provided simply as an alternative steam supply in case of insufficient supply from the source above-mentioned.

When the retorts are charged with coal, steam is admitted to the bottom of the charge at a temperature of from 200° to 800° C., "for the purpose of extracting

the ammonia after distilling off the oil." The distillate escapes from the retorts by the branch pipes mentioned above and enters the gas main D. Should the procedure in any one of the retorts be either too slow or too rapid, manipulation of the valves so as to allow an excess or a diminution of the hot steam can be effected. It is also stated that, with "careful attention to the battery, economy in heat is secured, and uniform work performed."

Two years later the inventor brought out another method of conducting the process of low temperature carbonisation, which consisted in previously pre-heating the coal, then passing through it the superheated steam; evidently the former method produced too much condensed steam in the form of water.

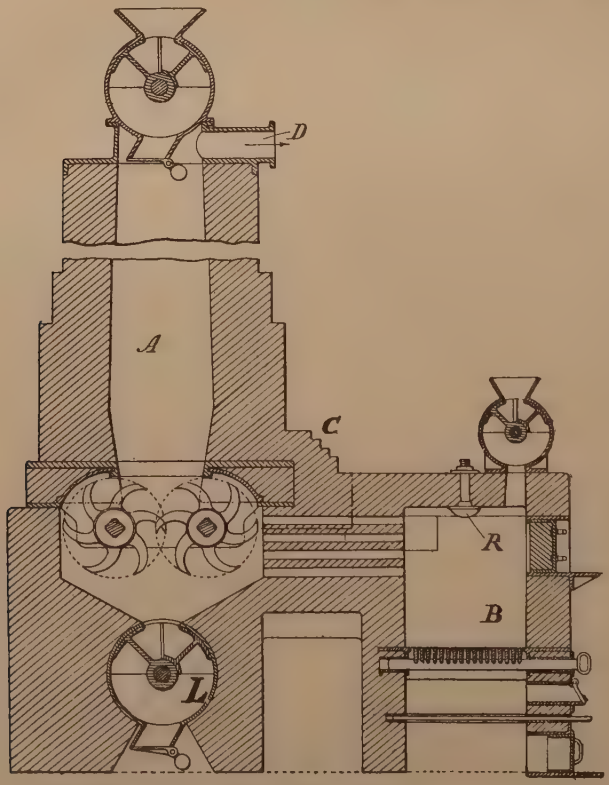


Fig. 284.—"Lamplough" Retort and Superheater.

The preamble to B.P. 124,294 states :—"According to this invention, the process for the distillation of coal consists in pre-heating the coal until gas commences to be given off, then passing superheated steam through the mass when sufficiently hot, as indicated by the giving off of the said gas; collecting the steam, together with the distilled products carried over with it from the still, and finally separating the said products."

The means for carrying out this project are shown in fig. 284, which is a vertical section through the apparatus, which consists of a vertical still *A*, and a furnace *B*; between the furnace and the vertical still are a series of apertures formed of brickwork, termed the superheater, fig. 284, through which

the products of combustion from the furnace, *B*, pass on their way to the still to heat the coal. The coal is charged in at the top of the still through the gas-tight filling apparatus ; the gases produced during the distillation are drawn off through the pipe, *D*. A set of two rows of toothed discs are provided at the bottom of the still for the purpose of drawing the charge downwards into the chamber below, from which it is delivered by the rotating apparatus, *L*.

The apparatus is stated to be capable of being continuously worked by feeding coal in at the top, and by discharging the product at the bottom after it has passed through the distillation process. The process can also, if preferred, be worked intermittently. When a charge of coal is filled into the still, the products of combustion from the furnace are passed through the superheater brickwork, and through the coal, until the temperature is sufficiently raised ; the products of combustion, along with the gases generated from the coal undergoing distillation, then pass away by the pipe, *D*, to the hydraulic main, the flow of the gases being assisted by means of a fan. When the coal is sufficiently heated in the still, and just when the volatile matter is beginning to be evolved from the charge, steam is admitted by the side-head, *R*, and the furnace is carefully closed, so that no free oxygen passes through into the still. Steam alone, or steam mixed with the furnace gases, passes into the still through the superheater brickwork, which is at a "relatively high temperature." The more volatile contents of the charge are distilled off at a temperature of between 300° and 600° C. When one charge has been completed the steam is shut off, and the temperature of the furnace is raised, until the partly spent coal in the still commences to burn to carbon monoxide gas. Steam is then turned on again, until the distillation is completed ; the products of this second operation, however, are taken away separately, and not mixed with the previous distillate ; these latter products are treated for the recovery of ammonia as sulphate ; the carbon monoxide gas is used for heating purposes. The spent coal in the still is now discharged from the still into the lower chamber ; the still above is then re-charged, and the process repeated.

When the continuous process is employed with the single process of distillation, the residual coal is discharged for the purpose of providing smokeless fuel, or it can be carried away by a conveyer to another still, where it will be subjected to the second process at the higher temperature, to recover the ammonia. It is pointed out that the temperature of the furnace during the process is low, "about 550° C., and the products of combustion of the fuel burnt in the furnace are carbon dioxide, and not carbon monoxide, products. When the steam passes over the fuel in the combustion space some of the products of combustion will generally mix with it, but, as stated above, steam alone may be passed through the pre-heated coal in the still. Neither producer-gas, nor water-gas, nor carbon monoxide, however, is made in the furnace and supplied to the still."

The Tozer Process.—The Tozer process consists essentially in the use of a certain form of retort which distinguishes it from other processes for the low temperature carbonisation of coal. The retort is made of cast iron, in vertical section and plan as shown in fig. 285. It is heated externally in a setting which is "specially designed and recuperative." It is the outcome of a great number of experimental trials by Mr. Marshall and Mr. Tozer, who state that, "A beginning was made with a battery of 10-inch tubular retorts, but the time required for complete carbonisation was too prolonged. These were scrapped, and 8-inch and 5-inch tubes were tried successively. The 8-inch was a failure, the time period being too long ; but the 5-inch brought us nearer to

the mark, *i.e.*, a short period of carbonisation, viz., some 4½ hours, with a temperature of 1,000° F.

"By this time the principle was established that to carbonise rapidly at a low temperature, the coal must be arranged in comparatively thin layers. Batteries of 4½ or 5-inch tubes are out of the question on account of the space occupied and excessive labour required in manipulation. Retorts of the 'slot' type would have to be of inordinate length compared with width to accommodate a workable charge; besides, in such an elongated cross-section they would, unless of great thickness, be incapable of resisting the pressure due to the expansion of the charge.

"The method hit upon to deal with the thin layers of coal was to distribute the same in the form of a circle or annulus, and a battery of retorts was erected on that plan. Success was immediately evident, but the charge was too limited in quantity. Then a second series of retorts was constructed with *two annuli*, one disposed concentrically within the other, and to convey the exterior heat of carbonisation through the first annulus of coal to the second or inner annulus, the annuli were divided by ribs into vertical sections or cells, advantage being

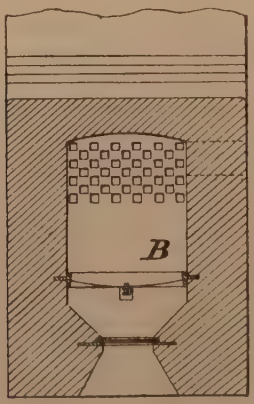


Fig. 285.—"Lamplough" Retort and Superheater.

Fig. 286.—Section and Plan of "Tozer" Retort.

taken of the conductivity of cast iron to induce these ribs (which extended the entire length of the vertical retorts) to conduct the exterior heat to the inner annulus. By dividing the coal in this way we find we can carbonise in 4½ hours, but (and this is most noteworthy) were we to distribute the coal contained in these two divided annuli into a single annulus of double the thickness, the time required for carbonising would be so prolonged as to render the use of a retort of that description commercially impossible. This is the whole theory of the retort in a nutshell." The process of carbonisation of coal in this form of retort is, the gases pass both upward and downward from the two annuli, and those gases that pass downward are gathered from both annuli into the central

tube of the casting, and ascend through a comparatively cold region to the off-take at the top, in the direction indicated by the arrows in fig. 286. The inventors put a special emphasis upon thus securing the gases as they are evolved at a low temperature, without being subjected to any increase of temperature while in the apparatus. They state that " when carbonising a coking, bituminous coal, the coke comes out in slabs of size practically the full height of the retort, and configuring exactly to the shape of the cells of the retort. If the coal is a non-coking one, the coke comes out almost in the same physical condition as the entering charge. The retort will deal with practically every description of carbonaceous material, coking and non-coking coals, shales, lignites, and peat, and in every physical condition, in size from 3 inches down to dust, and will carbonise and produce coke from colliery sludge or washings." The retorts hold about a quarter of a ton per charge, being considerably smaller than the original design, but other retorts are being made to carbonise 25 cwts. per retort.

In two installations contemplated, one on the Continent, and one in the Midlands, the former is capable of carbonising 200 tons of coal per day, and the latter 350 tons per day. In each of these installations the coke obtained is to be used for the production of power gas and ammonia.

These three processes are typical of the low temperature carbonisation process as practically carried on ; there are other processes, which do not differ very much from some of the above, which may be termed carbonising processes, where the coal is not burned for the purpose of heating it, such as the Del Monte process and others, where the apparatus has within the heating zone moveable machinery for shifting or turning the charge, producing complications and difficulties in the practical working.

There are other processes such as that designed by G. F. Bale and designated the " Universal Retort." The latter is a vertical retort and can be utilised for the production of smokeless fuel, or for the complete gasification of the fuel ; it is made of iron, encased by a brick setting, and fired with gas ; there is provision for the application of steam to the lower part of the charge, and means are provided for the automatic discharge of the residue by means of a ram at the bottom of the retort, operating in such a manner as to preclude the admission of air into the retort ; the charge of coal is admitted by means of a hopper with a cone-shaped gas-tight valve, under which is the off-take for the gaseous distillate.

There are various other retorts designed for low temperature carbonisation, embracing the gas producer principle ; one of them is the " Maclaurin Retort," which is practically an elongated gas producer of large capacity.

The Neilsen Process is another where no external heating is used, but " sensible heat " alone ; a low temperature carbonising retort is used, along with a gas producer ; the low temperature heating of the retort is accomplished by the " sensible heat " of the producer gas, with which, if the producer is working normally, the product will never be above 750° C. The producer gas is passed down through the charge in the retort, which distils off the light hydrocarbons. The residual coke in the retort can be used as smokeless fuel, or in the gas producer for forming producer gas and ammonia.

The retort is a tube placed at an angle and slowly rotated ; the charge of coal is fed in at the top, and the carbonised residue discharged at the bottom. The hot gas from the producer enters the lower end and meets the partially carbonised coal ; passing up through the charge it extracts the hydrocarbons from the coal, which pass out through the upper end into the gas main, through a dust and tar extractor to the condensing plant. The retort is said to be

7 feet in diameter at the feeding or top end, and 9 feet in diameter at the lower or discharging end, and is made up to 100 feet in length.

In the whole of the processes proposed for the carbonisation of coal at a low temperature, the chief object is the production of tar oils, a smokeless fuel, and motor spirit, and in some instances the complete gasification of the fuel into producer gas and ammonia.

But, as pointed out earlier in this chapter, it seems to be imperative, if these processes are to succeed as commercial propositions, to get the heat required gratis, and so to construct the apparatus that it will be less costly than some plants that have been proposed. There is no reason why a low temperature process (if it is necessary to produce what is claimed) should not be carried on in conjunction with a high temperature carbonising process, such as the manufacture of foundry or furnace coke in coke ovens, or in gas works ; in the former there are generally enormous quantities of waste heat to spare, or surplus gas ; even in connection with blast furnaces, where the gases are collected, the sensible heat of these gases would be sufficient for any of the proposed processes.

But at all events, for the production of smokeless fuel for domestic and commercial use, this must be carried on where it is most economical to do so, whether at the pit mouth near the coal, or in some manufacturing district where the gas, waste steam, or heat is to be had cheaply.

A low temperature process has this disadvantage, that it is a slow process, and that a number of the products it has to compete with in working are now in the market produced by other means, *e.g.*, oils, and motor spirit, and fuel ; it is therefore a commercial question as to the possibility of such a process being successful, even after it has been perfected scientifically.

The low temperature process produces certain oils and residues which are not produced by the high temperature process, but on the other hand the high temperature processes are all a commercial success, both for making foundry and furnace coke, and for the manufacture of gas, and they are indispensable. The low temperature processes cannot compete with the high temperature processes in any of the products made by it, such as gas, motor spirit or ammonia. It is therefore a question of very economical working, possibly in conjunction with a high temperature process, with a view to the production of oils, and possibly smokeless fuels, that the low temperature process will survive. As pointed out previously, a plant could be very easily designed to fit in with the high temperature process, where the costs of heating, labour, administration, and other expenses would be brought down to a minimum. There is scope for any of the processes which have been put forward to work in combination with a high temperature process, when every item could be profitably obtained that is produced from coal by both high and low temperature processes.

The following are some of the results obtained by low temperature carbonisation—that is, below 1,200° F.—as given by Mr. Marshall :—

Some Results obtained by Low-Temperature Carbonising at under 1,200° F.

Name of Coal.	ANALYSES.										YIELDS PER TON OF COAL CARBONISED.							
	Coal.					Tarless Fuel.					Spirit.	Light Oils.	Heavy Oils.	Total Oils.	Tar Acids, Cresylic.	Pit Pitch	Sulphate.	Tarless Fuel.
	H_2O.	V.M.	F.C.	Ash.	N.	H_2O.	V.M.	F.C.	Ash.	N.								
											Galls.	Galls.	Galls.	Galls.	Galls.	Cwts.	Lbs.	Cwts.
Ballengleich (Natal),	3·34	25·10	53·65	19·0	..	3·7	9·85	63·11	23·34	..	3·25	3·9	4·0	15·2	1·8	0·34	36·5	16
Forest of Dean,	3·1	31·2	58·57	7·0	..	dry	12·9	78·4	8·7	..	2·0	5·7	5·4	15·2	..	..	13	15·9
Hulton,	dry	34·73	50·06	7·21	..	dry	8·26	82·85	8·89	..	0·83	4·9	7·9	18·4	..	..	20·7	14·7
Maltby Main,	13·0	29·2	..	8·9	..	..	..	..	11	..	4·50	5·7	4·7	16·3	..	..	9·5	14·5
Silkstone, Beanshaw,	..	30·9	..	..	..	..	8·0	81·6	10·4	..	5·06	6·0	6·1	17·2	..	..	..	..
Silkstone Winter Slack,	dry	32·85	58·31	8·84	..	dry	7·71	82·3	9·99	..	0·4	4·4	10·5	19·8	..	..	12·1	15·5
Silkstone, Two Foot Slack,	dry	32·96	57·39	9·65	..	dry	8·08	75·52	16·4	..	0·5	5·0	11·0	22·0	..	..	10·91	15·75
Niddrie Cannel,	dry	50·87	44·4	4·73	..	..	..	..	..	..	5·0	12·0	19·0	..	..	2·37	17·4	10·0
Newbattle Cannel,	1·14	50·23	44·06	4·33	..	..	..	..	..	..	5·0	13·5	28·5	..	..	2·06	21·8	10·0
Hucknall Belt Pickings,	3·8	21·2	43·7	31·0	..	..	..	..	34·0	..	2·2	7·52	2·27	14·2	..	0·39	11·0	14·4
Sulphide Corporation (Australia),	2·08	31·8	55·9	8·43	1·75	..	10·3	75·4	18·26	1·95	5·37	..	8·0	16·4	..	0·67	19·8	15·5
Bignall Hill Washed Pearls,	..	..	..	5·4	..	..	..	..	7·4	..	2·5	5·7	4·0	22·0	..	0·8	23·8	14·0
Tilmanstone (Slack) Kent Coal,	..	..	..	..	..	..	..	..	12·5	..	2·5	6·0	4·5	20·3	..	63·5 %	22·0	16·0
Snowdon (Kent Coal),	..	..	..	..	..	..	..	..	13·8	..	3·0	8·0	3·9	17·3	..	62·0 %	19·2	16·0
Stanton Iron and Coal Company (Cannel),	..	..	..	..	..	..	..	..	..	..	7·6	7·92	11·88	44·0	3·08	..	25·33	10·0
Wigan (Cannel),	1·64	57·82	36·61	3·93	..	2·25	7·96	82·77	7·02	1·30	6·8	14·7	44·7	85·1	8·0	1·15	22·0	10·0
Lignite (Spanish),	5·24	35·74	..	9·99	1·30	..	12·50	15·60	..	1·24	2·2	4·4	6·95	22·71	..	..	18·5	11·0
Shale (Spanish),	..	..	..	..	..	..	..	..	..	..	1·1	1·2	17·00	30·1	..	..	19·1	worthless.
Glapwell (Slack),	..	..	..	..	..	..	..	..	..	..	3·54	5·03	5·40	17·96	13·0	..	18·6	16
Glapwell Nuts,	..	..	..	..	..	..	..	..	..	..	4·39	10·17	8·39	28·69	..	..	10·2	15·5
Tyne Boghead Cannel (Mickley),	..	..	..	..	..	..	..	..	..	..	3·12	14·9	19·94	53·5	..	..	23·0	14·0

NOTE.—In addition to the production of spirits (petrols) obtained from the fractionation of the tar oils, an additional 2 to 4 gallons per ton of coal carbonised will be obtained by "stripping" the rich gas, which must be added to that tabulated in this statement under Column A.

Cokes.—The cokes contain from 7 per cent. to 12 per cent. of volatile matter.

Tar Oils.—These fractionate into tar acids (creosols), and represent (approximately) 7 per cent. to 14 per cent. of the crude oils. The oils contain 5 per cent. to 8 per cent. of paraffin wax.

EXTRACTS FROM REPORTS OF GOVERNMENT RESEARCH DEPARTMENTS ON LOW TEMPERATURE CARBONISATION.

The Lords of the Committee of the Privy Council for Scientific and Industrial Research have had the subject of Low Temperature Carbonisation under consideration for some years; they erected a plant for this purpose, which has been in continuous operation since December 27th, 1925, and till December 27th, 1926, had carbonised 1,350 tons of coal.

The retorts were inspected and one was stopped for this purpose and emptied for two hours, the others on two occasions; otherwise continuous working was maintained.

The system employed will be fully explained by the details taken from the Report of the Director, Mr. C. H. Lander, D.Sc., M.Inst.C.E.,* which are as follows:—

"The present form of retort has been evolved after considerable experience with a setting of four cast-iron retorts, from a design based on Scottish shale practice, and described and illustrated in the Report of the Fuel Research Board for the period ended 31st December, 1924. They are known as the "B" retorts, and are 20 feet high × 9 inches × 2 feet 4 inches at the top, widening to 1 foot 3 inches × 2 feet 9 inches at the bottom. It was thought that these retorts were too wide along their minor diameter, and that the heat penetration would be improved by reducing the thickness of coal under treatment. There seemed to be no objection to lengthening out the major diameter; consequently, a second setting of two cast-iron retorts, 21 feet high × 6 feet 6 inches × 4 inches, widening to 6 feet 10 inches × 8 inches, was erected. These are known as the "D" retorts, and are so referred to in the Annual Report for 1925. When these narrow retorts were designed, provision was made for making them wider by the insertion of a 3-inch distance piece along the vertical axis between the two halves of the retorts. A setting of such wider retorts, the "E" retorts, was also put in hand, but its completion was delayed until experience had been gained with the narrow retorts.

"In an endeavour to make the fullest use of the heating gas in connection with these narrow retorts, arrangements were made whereby the spent gases were deflected against the retorts at two positions in the vertical height, while the top of the setting acted similarly in a third position. Unfortunately, when using the amount of gas which was necessary for the desired working temperature, it would appear that the flames were so long that they themselves, or gases at almost flame temperature, were deflected against the retort, and that this soon led to local overheating and distortion of the retorts.

"Before this occurred, however, it was proved fairly conclusively that the retort was too narrow to allow of the continuous passage of small coal, if of caking or medium caking quality. If the whole charge were allowed to carbonise completely without movement, then there was no difficulty whatever in withdrawing the coke.

"The coke thus formed was of excellent quality, but the yield of tar was very low, owing apparently to the long distance that the vapours must travel in order to get to the offtakes either at the top or the bottom of the retort, or to additional offtakes inserted into the charge.

"There was no difficulty whatever in carbonising non-caking coal of any

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size in this retort, and it is quite possible that sized caking coal could be worked satisfactorily, but unfortunately the retorts were distorted before this stage of the investigation was reached. After the retorts had become distorted it became impossible for any coke in block form to travel through them.

" The distortion first showed itself by causing the joints to leak and so allowing coal gas to escape to the combustion chambers. After this happened it was not long before this extra flame burning immediately against the walls of the retort made it unworkable.

" The two wider retorts (the " E " retorts), which have now been in use for 12 months, are 21 feet high × 6 feet 6 inches × 7 inches, widening to 6 feet 10 inches × 11 inches. They are made of ordinary grey cast iron of good quality, and are divided into three sections, which are cast in halves. The metal is 1 inch thick, and strengthening ribs project as far as the edge of the flanges along each side of the retort. The general construction is shown in the drawing, fig. 288.

" The extractor gear consists of a curved grid or comb (A), which supports the charge at the base of the retort. This design was adopted after discussions with Messrs. Woodall, Duckham & Co.; certain of its features are embodied in patent No. 251,043 of that firm. Behind this revolves a set of arms (B), which, passing between the teeth of the comb, push the coke off them. A rush of coke is prevented by weighted bars (C) suspended so as to rest against the ends of the teeth, as shown in the diagram. Arrangements are made to allow of rodding vertically up through the teeth of the extractor gear and also horizontally in a position above the teeth.

" As originally designed, it was intended that the extractor gear should be worked continuously, and therefore the coke chamber below the extractor gear was divided by a door (E), the intention being that when the door was closed the coke below it should cool off for a period of, say, 1½ hours while the hot coke was collecting above the door. When the cooled coke had been discharged, the hot coke would be allowed to fall into the lower chamber to cool, and the upper door again be closed.

" In actual practice it has been found more satisfactory to operate the extractor gear for a short time only at intervals of one, two, or three hours, according to the nature of the coal undergoing carbonisation, consequently, the inner door of the coke chamber is not used.

" Steam can be admitted to the coke chamber (at F) immediately above the doors. With the use of steam so admitted there are indications of an increased yield of tar, but beyond sealing the retort from inrush of air the exact function of the steam is uncertain. This matter is under investigation at the present time.

" Above the heated zone there is a short casting 18 inches high, of the same general dimensions as the upper portion of the retort from which the offtakes ascend, and in the cover of which are six rodding holes and the coal supply valve. The casting is not shown in the diagram, as it is being removed and the cover of the retort placed immediately on the top of the heated zone. This step has been decided on in order to obviate as far as possible the condensation of the tar vapours on the cold coal entering the retort.

" Various systems for admitting coal to the retorts have been tried; for example, two feed valves feeding into the side of the upper casting, two feed valves on the top of chutes placed directly over the retort. The system at present in use is the most satisfactory so far -that is to say, one feed valve

(H) in the centre of the cover of the retort, the valve itself being as close as possible to the heated zone.

"Two gas offtakes (J) are arranged one at each end of the major diameter of the retort, and these discharge into the top of the collecting main (K) with as short a connection as possible. Arrangements are made for continuous circulation of liquor through the collecting main, which may be kept wet or dry as required.

"Use was made of the experience gained in connection with heating the narrow retorts when the wider retorts were completed. The heating is arranged on a system which at the Fuel Research Station has been found particularly successful—namely, the fuel gas is led by means of plain steel pipes (L) bent vertically upwards at the end into various corners built into the internal face of the setting. It was found that the chimney effect of the corner enables the flame and hot gases to cling closely into the corner and not to wander, and so contact with the retort walls is avoided. The heat from the flame is conducted along the brickwork, so that the retorts are heated very largely by radiation from the flame and brickwork. It appears certain also that the waste gases must heat the retorts by convection during circulation inside the setting before leaving the chamber after their first passage direct to the top. There are three sets of this type of burner, dividing the vertical height of the retorts into three portions.

"The air supply is led to intermediate positions (M) between the burners at each level, the idea being to retard the rate of combustion of the gas and to lengthen the flame. In the top position the air supply discharges close to the burners so as to shorten the flames.

"The number of burners at each level is 16, and the number of entrances for the air for each set of burners is 6. They are arranged as shown in the diagram. Half-way along each side of the setting a $4\frac{1}{2}$-inch vertical projection of brickwork is built. One gas burner is placed in each corner of the setting and one in each corner made by the projecting brickwork. This leaves the centre of the setting unheated, and there it is necessary to build a cross from the floor upwards to give four more corners into which the burners may be placed.

"Apart from such support as is necessary for the gas and air pipes, which are 1-inch and $1\frac{1}{2}$-inch steel tubes respectively, the inside of the setting is perfectly plain from top to bottom and contains no obstructions to the upward passage of the gases.

"The combustion chamber is closed in at the top by a steel plate, which is made gastight by a special sand seal (N), which allows of expansion or growth of the retorts to the extent of 6 inches. The seal plate is covered over by 3 inches of non-conducting brick and a further 3 inches of sand.

"The flue gas offtakes lead from the centre of the seal plate into one 8-inch pipe (not as shown diagrammatically in the sketch), which passes away through the roof, rising 21 feet above the top of the setting. The pull thus exerted on the setting is sufficient to draw in the air required for complete combustion of the heating gas.

"The extractor gear is driven by a dragbar which is connected up to the gear of the adjacent setting of Glover-West retorts. The motion is conveyed to the extractor by an adaptation of the standard Woodall-Duckham arrangement. The lever of the gear is thrown into action by the operator from the top platform. When he wishes to extract the coke from the retorts into the cooling chamber, he pulls the lever into its working position for each stroke by means of a wire. In this way he can watch the effect which the extraction of the coke

at the bottom has on the upper portion of the charge in the retort. When the coal has fallen sufficiently far from the top of the retort, the lever is allowed to remain out of gear and a fresh charge of coal is run in through the coal valve.

" By suitably arranging the charging periods it has been found possible to reduce the rodding necessary to a minimum. Except for charges containing a large quantity of coal smaller than $\frac{1}{2}$-inch pieces, no rodding is necessary.

" It was considered at first that the most suitable coal for use in these retorts would be either a medium caking coal or a blend of caking and non-caking slacks. Experiments were carried out on such blends until the end of June. The maximum throughput thus reached amounted to 3·0 tons per retort per day.

" When the supplies of non-caking slack coal ran out at the commencement of the coal stoppage, an attempt was made to reduce the caking power of strongly caking slack coal. This was done by passing the coal through the narrow (" D ") retorts, the combustion chambers of which were kept at 340° C., at such a rate that it was dried and preheated to a temperature of 180° to 200° C. During the preheating, air was allowed to pass up through the charge. The oxidation thus effected was found to be slight, and eventually carbonisation of untreated caking coal was attempted.

" By this time the only coal available was that remaining in stock at the station, except for Durham coal, which was supplied by the South Metropolitan Gas Company from their reserve stocks until a few days after the end of the coal strike. Fortunately, however, the coal available included non-caking, medium caking and strongly caking varieties, the two former being in lump size, and of the latter some being nut coal and some run of mine with the larger lumps broken to pass through $2\frac{1}{2}$ inches. All these coals have been worked through the retorts quite satisfactorily. It was noticeable, however, that the ease of working, throughput, and yield of tar increased in proportion to the length of time that the coal remained in lump form in the retort, although there was not sufficient coal available to yield actual figures to prove this.

" Thus non-caking nuts were the easiest to work, gave the highest yield of tar, and would give the greatest throughput. Slightly caking nuts would probably approach this very closely. Strongly caking nuts required no rodding, and gave a good throughput and a good yield of tar. With a mixture of lump coal and fines some rodding was necessary, and the rate of throughput and the yield of tar depended on the proportion of fines. With fine coal both the throughput and yield of tar were low, and rodding amounting to possibly eight minutes per two hours was necessary on each occasion of charging.

" It was found that the fine coal (through a $\frac{3}{8}$-inch screen), which amounted to 50 to 60 per cent. of the Durham coal used, could be dealt with by briquetting. Several tons of ovoid briquettes were made with 4 to 6 per cent. of pitch as binder, and it was found that these briquettes, when mixed with the lump coal, could be carbonised at an increased throughput. When, however, the briquettes were passed through the retorts by themselves, the coke formed was so hard and strong as to be difficult to extract. The small coal was, therefore, mixed with varying percentages of breeze prior to briquetting. Of these mixtures, 20 per cent. low temperature coke breeze, 74 per cent. coal, and 6 per cent. pitch, was the most satisfactory. These briquettes passed through the retort at a good throughput and formed excellent coke.

" The coke from the fine Durham coal was very strong, hard and compact, and arrangements have been made to test its suitability for foundry purposes.

" The retorts have been at their present working temperature of 625° C.

since March 27th, 1926. The temperature is gauged by two pyrometers in the combustion chamber, each of which has three junctions which are severally opposite the centre of each vertical section of the retort. These are as originally designed, and it is possible to move them up and down in a vertical direction over the height of the sections to which they are adjacent. It became evident when the retorts had been at work for some time that a really close temperature control could only be obtained by having the thermocouple tubes in actual contact with the metal of the retorts themselves. However, as the retorts were in use, all that could be done in this direction was to drill holes through the top flanges of the retorts and pass one thermocouple down as close to the retort as possible. It could not pass beyond the bottom flange of the first section, so that there is now, in addition to the thermocouples in the combustion space, one thermocouple tube actually touching the metal of the top section of each retort.

" When working smoothly, the retorts are charged alternately, and it has been found that there is no necessity to alter the gas supply in any way. If, however, trouble is experienced with the coal in the retorts, then it is very convenient to be able to reduce the gas supply to the top section of the retort; that to the lower parts of the retort very seldom has to be altered.

" The amount of fuel gas required may be judged by the following figures for operation on run of mine Durham coal without steam, at the rate of 2·7 tons per retort per day :—

	Water Gas per Hour.
Lower set of burners, ...	1,050 cubic feet.
Middle set of burners, ...	420 ,,
Upper set of burners, ...	1,000 ,,

" The table at the end of the report gives the results of such tests as it has been possible to carry out in the difficult circumstances caused by the coal stoppage. It was impossible to secure uniform supplies of coal in quantities sufficient for the extended tests which are necessary to obtain thoroughly reliable figures of yields.

" It is considered that the calorific value of the gas as shown in the table can be improved, as the unusually low values shown in some cases are due to admixture with air which leaked through the joints of temporary retort covers.

" Both of these wider retorts were emptied for examination at the end of December. There are distinct evidences of bulging, especially towards the bottom of the retorts, but not to such an extent as to prevent their working.

" The Cast Iron Research Association has been asked to assist in obtaining castings which will not distort at a working temperature of 625° to 650° C., with the result that one retort having the same general overall dimensions, but of special design and special metal, is under construction. It will be placed in a setting with one of the narrow retorts which is being renovated, and it is hoped that a satisfactory comparison may result.

" The programme to be resumed, now that reliable supplies of coal are available, includes testing the wider (" E ") retorts as a means of carbonising strongly caking, medium caking, and non-caking coals with a view to ascertaining the optimum size of coal and the optimum conditions under which the retorts should be worked. A comparison will also be made with the other retorts to see which is the most suitable for the carbonisation of non-caking coals and briquettes."

TABLE.—Showing the Results of such Tests as it has been possible to carry out in the difficult circumstances caused by the coal stoppage.

Temp. of setting. °C.	Coal.	Duration of test. hrs.	Throughput per retort per day. tons.	Gas. Cu. ft. per ton.	Gas. Calorific value. B.T.U. per cu. ft.	Gas. Therms per ton.	Tar in gals. per ton.	Coke. Cwts. per ton.	Coke. Breeze per cent. through ½-in. square mesh.	Coke. Volatile matter less moisture. On ½ in. per cent.	Coke. Volatile matter less moisture. Through ½ in. per cent.	Remarks.
625	Durham (run of mine): through ½-in., 40–60 per cent.	120	2·69	5,420	710	38·48	11·1	15·04	18·8	6·9	8·3	Charging at 2-hour intervals; difficulty encountered with No. 2 retort only; rodding at the bottom of No. 2 retort necessary for discharge of coke.
610	Durham (run of mine): through ½-in., 52 per cent.	97	2·74	5,750	660	37·95	11·2	14·12	10·6	6·7	8·6	Retorts charged at 3-hour intervals; slight rodding at the tops and bottoms of retorts necessary.
625	Crushed: 48 Butterley, 52 Wearmouth.	92	3·03	6,840	547	37·41	11·9	14·59	20·8	7·8	10·2	Retorts charged at 1-hour intervals; trouble was experienced only for a short period on the third day in retort No. 2, when the coke was inclined to hang.
620	Nut coal, Mitchell Main (cold).	96	3·52	4,860	·729	35·45	13·1	15·30	11·9	8·4	12·3	Retorts charged at 2-hour intervals; easy working; no trouble.
605	Screened on ⅜-in. round mesh, Durham: through ½-in., 27 per cent.	120	3·31	5,890	681	40·11	14·1	15·53	13·0	7·2	9·2	Retorts charged at 2-hour intervals; No. 2 retort gave trouble on second and fourth days of test, but no trouble experienced with No. 1.
625	Nut coal, Mitchell Main (preheated).	96	4·05	4,460	752	33·54	14·31	15·88	11·5	7·3	11·4	Retorts charged at 2-hour intervals; very easy working; no rodding required.
625	Dalton Main Nuts: through ½-in., 35–43 per cent.	74	3·66	5,190	719	37·3	17·3	15·14	17·2	6·6	8·2	Retorts charged at 1-hour intervals; very easy working; no rodding required.
625	Garforth Nuts: through ½-in., 18 per cent.	72	3·38	6,150	577	35·5	18·4	12·89	19·5	7·7	10·1	Retorts charged at 1-hour intervals; very easy working; no rodding required.
610	Briquettes: 74 per cent. Durham coal; 20 per cent. low temp. coke breeze; 6 per cent. pitch.	72	3·03	5,160	557	38·54 (on dry coal and pitch)	13·8	15·51	12·0	6·9	8·0	Retorts charged at 2-hour intervals; no serious difficulties in working; No. 1 retort gave a little trouble during last day of test.

The Chairman of the Government Fuel Research Board also states in his report that "considerable progress has been made, both at the Fuel Research Station and elsewhere; much consideration has been given to the best method of carrying any suitable process to the final stage of its development—namely, a test under strictly commercial conditions, and on a commercial scale, extending over several years. Those processes which produce the largest proportion of lump coke suitable for domestic use also produce considerable quantities of rich gas, which forms a valuable portion of the products of carbonisation. If such a process were to be adopted throughout the country very large quantities of gas would be produced, the full value of which could only be realised with the co-operation of the gas undertakings. It was accordingly decided by the Government, with the concurrence of the Fuel Research Board, that Mr. (now Sir David) Milne Watson, the Governor of the Gas Light and Coke Company and the President of the National Gas Council, should be asked for his assistance in this matter.

"Questions of commercial development are somewhat outside the scope of the Department of Scientific and Industrial Research, and it was accordingly decided that the matter should be handled by the Mines Department, with the Department of Scientific and Industrial Research as technical advisers. Mr. Milne Watson was asked whether he was prepared to consider all existing processes in detail and to advise the Government:—

"(*a*) Whether, in his opinion, any of these processes had reached such a point of development that it was worth while for his company to continue the experimental development on a large scale.

"(*b*) If so, whether he considered the selected process or processes sufficiently promising to justify his company in taking the entire risk of this development.

"(*c*) If not, whether he would submit a scheme, after discussion, whereby the Government would be asked to bear a part of the risk involved."

Mr. Milne Watson agreed to go into the matter, and after he had received reports from his staff after examination of all the processes being developed, both in this country and on the continent, he reported that he considered the one developed at the Fuel Research Station was the most promising for development in conjunction with gas works. He did not consider that any process was so far proved as to justify his company in taking the whole risk of its development, but he was so far impressed with the desirability of co-operating with the Government in putting the matter to a practical test as to offer a site for a 100-ton-a-day plant, and to erect the plant and run it as continuously as was reasonably practicable for a period of three years, and to carry out experiments and researches in connection with the original cost of providing and erecting the new plant necessary on the selected site, which already had many of the requisite conveniences (the Richmond Gas Works at Richmond, near London), viz.:—It was finally arranged that a subsidiary company should be formed, termed the 'Fuel Production Company, Ltd.,' the capital of which has been guaranteed under the Trades Facilities Act. The Gas Company will act as managers for the Fuel Company, and will bear all running and management costs. At the end of 1930 the Gas Company have an option to purchase the plant, or, if they do not wish to do this, they will clear the site and dispose of the plant, etc., on behalf of the Fuel Company. Details of the plant are now being worked out.

" It has been agreed that the company shall keep full records of experiments and all statistics necessary to demonstrate the results obtained, and to keep proper accounts in connection with the business of the Fuel Company. The Mines Department have the right to inspect the accounts, and the Research Department has the right to inspect the plant, its working, and all technical records.

" This arrangement should give definite information as to the commercial possibilities of the process."

The Royal Commission on the Coal Industry (1925) paid considerable attention to this matter of Low Temperature Carbonisation, " and took evidence from various independent workers on the subject." In their report they state, " We have given close attention to the question of low temperature carbonisation, but can find no evidence that the system has yet been anywhere established on a commercial scale for a period fully tested."

" The tar obtained by low-temperature carbonisation of coal differs considerably both from gas or coke-oven tar, and from natural crude oils; there is still much to be learnt as to its composition and the best method of treatment.

" Where bituminous coal is heated in a current of inert gas, oil first appears at from 210° to 250° C., and continues to be evolved even if the temperature be not raised further. These figures have been observed at the Fuel Research Station, and are considerably lower than the temperatures at which oil appears when the coal is heated in still air. In practice it is impossible to heat a mass of coal in a uniform manner, and the tar vapour when formed from any particle of coal must in general come into contact with other coal, or coke, at either a higher or lower temperature, and only after a more or less lengthy passage can it be collected and condensed. During this passage it may be either condensed or decomposed, according to circumstances. It is, therefore, practically impossible to obtain any considerable quantity of tar in the condition in which it is actually given off from the coal."

Both the Low Temperature Carbonisation Company, Limited, and the Government have abandoned the retorts made of fireclay and have installed a set of iron retorts; but, according to the report, these have given trouble by distortion; it is probable that this is due to the weight of the retort itself together with the weight of the coal charge acting upon the iron at so high a temperature as 650° C., which is a dull red heat.

There is no doubt that iron inside a furnace exposed to heat cannot be depended upon to withstand distortion.

It seems that the reason for the abandonment of the clay retorts was the loss of gas through the joints, and this taking fire in the heating flues increased the temperature considerably, with the loss of the valuable gas; the working temperature of 650° C. is too low to coke the oil tar given off at that temperature in the joints of the retort, as happens in the high-temperature process of gas making; in the latter process the tar given off at the higher temperature contains heavy pitchy hydrocarbons, which, passing through the cracks and

fissures in the clay retort, soon cements them up, and the retort becomes perfectly gas-tight.

The abandonment of the clay retort is regrettable, because it is more suitable for permanent work at a temperature of 650° C.

The author suggests a form of setting of retorts, whether of clay or cast iron, or even steel, that might prove efficient at a temperature of 650° C., by constructing the retorts for the manufacture of low-temperature fuel and rich gas, together with producer gas apparatus. It is a fact that in an ordinary gas producer the gas given off, consisting principally of carbon monoxide and hydrogen, leaves the producer at a temperature of about 650° to 750° C. The retorts can be so arranged in the setting with the gas producer that they could be heated by the initial heat of this producer gas, while any leakage into the heating flues would not matter, since there is no combustion taking place in these heating flues.

Should this method be adopted on the same lines as obtain in gas works practice, of working the retorts on an even pressure with that in the heating flues, no loss of gas from the retorts would ensue.

It is quite an easy matter so to arrange the air and steam pressure on a gas producer as to ensure a perfect stream of gas at a definite temperature of, say, 650° to 700° C. Iron retorts could be used, but preferably those made of steel tubes, as being stronger and not so liable to soften with the heat. Should the gas from the producer be as it ought to be, it would have no deleterious effect on the steel. The author in 1901 patented a furnace (B.P. 1910) in which he has kept fine steel wire in a current of producer gas for hours at a temperature of 750° C. without producing the slightest effect upon it.

In the working of such a combination the producer gas can be mixed with the retort gas, after the latter has been subjected to the ammonia and benzol process, and a very good gas be produced for most heating purposes. This would effect an economy in the heating of the retorts, together with the production of a saleable gas.

The steel tube retorts could be installed at a very much lower cost than cast-iron retorts, as these latter require to be made of a specially pure iron, in order to keep their shape under heat; the former need only be less than half the weight of the cast-iron retorts; they will possess other advantages by having a fine, smooth surface, and could be made in one piece, of any length or shape required. But it must be observed that they cannot be heated in the ordinary manner by means of combustion in the flues, otherwise they would soon be oxidised and destroyed, but being heated by the initial heat of a gas charged with carbon, the steel remains intact.

CHAPTER XIV.

THE ECONOMIC COMBUSTION OF FUEL.

In the foregoing chapters dealing with the development of the coke oven and retort settings for gas manufacture, it will have been noticed that solid fuel has been abandoned in favour of gaseous fuel, and the economical application of gaseous fuel has marched side by side with the development of the furnace; the heat, formerly lost by escaping with the products of combustion into the chimney, is now recovered. Vast progress has been made in recent years in connection with the economical working of furnaces, and in the saving of fuel, effected by the application of regenerators or recuperators, both for the heating of the air and the gas, abstracting the heat from the waste flue gases. A further economy was also made by introducing into a gas producer a certain proportion of the waste gases containing CO_2, which is converted into CO with less expenditure of raw fuel than when atmospheric air alone is blown in.

The use of gaseous fuel is also more economical than raw coal or coke for certain purposes, and for the attainment of high temperatures is indispensable for heating furnaces, apart from smelting processes, where carbon is required as a reducing agent.

It is questionable if the use of round fuel such as coke or coal in the blast furnace is the most economical method of obtaining pig-iron. The author, a few years ago, made certain experiments on the reduction of metals from ores, by comminuting the ore, which was in the state of oxide, with waste coke or anthracite duff; he briquetted the mixture with a certain amount of caking coal duff, in the apparatus described in a previous chapter. Surprising results were obtained in reduction of the ores of zinc, over 5 per cent. more metallic zinc being obtained beyond that recovered by the ordinary process. His process for reducing ores is in forming an intimate mixture, in a fine state of division, of the oxidised ore and the carbon for reduction, whereas in the ordinary process above mentioned for the reduction of zinc the carbon (usually anthracite) is in the size of peas or nuts, and the reduction of the metallic oxide is, therefore, mainly accomplished by the action of carbonic oxide gas, and as the process is a comparatively lengthy one the carbon gets spent, and the carbonic oxide begins to lose its reducing power as the ore passes, more or less, into a silicate, during the distillation. By the proposed new method, intimate contact is made by each particle of the metallic oxide with a finely divided film of carbon, and the reduction is more rapid, and is accomplished at a much lower temperature, thereby saving fuel in heating and carbon in reduction, with a much larger throughput in a given time.

The author proposed to treat the ores of iron by a similar process, for the purpose of saving a large percentage of the fuel now employed in producing iron and steel, and for the elimination of silicon, but the exigencies of the Great War prevented his carrying out these experiments.

It may be that this proposition will be taken up by others in the near future, as the subject is a very important one, and any means of reducing the cost

of production, saving fuel, or improving the quality of the iron or steel will be welcomed.

This matter is mentioned here, as the proposed process is one in which low temperature carbonisation is used in the briquetting of the ore, whereby the intimate contact of the oxidised ore and carbon is made, requiring a lower temperature than that now employed in the blast furnace for reduction. It would, however, be out of place here to go more fully into this matter, as metallurgy is outside the scope of this work.

A large amount of the fuel now used is wasted by the methods employed for its combustion, but the amount of waste is less than obtained a few years ago. There have been a number of improvements in the firing of furnaces, whereby smoke has been prevented. All smoke issuing from furnaces or domestic fires is waste, and fuel of any kind can be burned without the emission of smoke, if the furnace is properly constructed, and the fuel is fed in a manner explained further in the following

It very often happens that, given a first-class furnace grate for firing a steam boiler, the furnaceman, instead of feeding his fire with reason and care, will heap on a large quantity of raw coal; this will not burn, but will produce gas in the form of smoke, which will be lost up the chimney. This is due to the fuel being cold, and being heaped up on the fire: the heat of the incandescent fuel underneath, while heating up the cold charge of coal, carbonises that part of it in immediate contact with itself, distilling the hydrocarbons and resulting in the loss of very valuable heating gas such as carbonic oxide and hydrogen. A double loss is thus created in the furnace: first, by the waste fuel passing away as smoke unburned, and secondly, by the chilling effect of the cold fuel on the surrounding furnace, lowering the temperature, until the new charge of fuel has been heated up to the point of ignition of the gas, when it will commence to flame. The proper method of feeding a furnace is to feed it with a small quantity of fuel at a time, just as much as the heat of the incandescent portion of the fire is capable of heating up immediately, and to consume all the gas emitted; but this means constant attention with hand-fed furnaces. This has to a large extent been overcome by mechanical stoking, by means of which a small quantity of fuel at short, regularly-timed intervals is thrown upon the fire, causing no smoke, and effecting a saving in fuel and labour.

The design of the furnace is also a great factor in the saving of fuel, and efficiency in heating, especially with those furnaces designed for the introduction of heated air, thus saving the fuel otherwise expended in heating the air for combustion up to the point of ignition. This is often accomplished, as shown in previous chapters, by abstracting the heat from the waste gases escaping as the products of combustion from the furnace before they reach the chimney shaft.

In the heating of boilers with long tubes, raw coal is used; coke cannot be so economically used, because coke does not flame, except when fed upon a sufficiently deep bed of fuel, so as to change the CO_2 produced upon the furnace bars into CO, which will burn on the top of the coke: but this is very uneconomical with regard to heating power, since the temperature engendered in the lower part of the furnace is expended in converting the CO_2 into CO; the latter gas can only be perfectly burned if heated air is also admitted into the upper part of the furnace chamber; this often is not possible, and under these circumstances the CO gas passes away unburned, with an inevitable loss of fuel. Coke, however, is successfully used for local heating with a shallow fuel bed, where the full temperature can be developed by the combustion of the

fuel to carbonic acid gas. Thick beds of fuel are, therefore, wasteful: thin fuel beds require more attention, with hand firing, but with the mechanical stoker they should be the rule.

When the mechanical stoker is properly designed so as to convert the fuel to CO_2, nothing more can be desired from an economical point of view; there are many forms of these stokers now working excellently, with a great saving of fuel compared with former methods of hand firing.

With regard to the fuel consumed in the domestic grate, there has not been the improvement here which has been made in recent years with the furnace for steam raising and other purposes. A great number of domestic fire-grates could not be worse designed from an economic point of view in fuel consumption. The open fire-grate, designed originally no doubt to burn wood, is totally unfitted to burn coal properly; nine-tenths of the domestic grates produce smoke, therefore waste of fuel; they are built into a chimney breast where the air of the apartment, drawn by the chimney draught into the front bars of the grate, consumes the fuel in the front, and distils the fuel at the back. The fire is also heaped up with raw fuel. The distillate, in the form of smoke, is in reality valuable gas, which escapes unburned into the chimney, with loss of heat and fuel. The domestic grate being only open to admit air for combustion in the front, the bottom bars are scarcely noticeable, being most of the time closed up with cinders, very little air passing through them, unless they are constantly cleaned with the poker. The sides and the back are generally closed by means of a fireclay brick or slab; the fuel against these cannot be consumed in the same manner as that immediately against the front bars, and, as the radiation of heat proceeds from the front, a fire-grate charged with a considerable thickness of fuel is very uneconomical; the fuel in the rear of the grate is converted to CO, which is never consumed until the fire with its load of raw fuel is burned to incandescence, or, in other words, as long as smoke is emitted there is loss of fuel and heat; smoke is very difficult to burn, unless there is a good supply of hot air, which is impossible in the open domestic fire-grate.

The above is what happens in burning raw coal; also all the valuable volatile constituents, such as tar, ammonia, and benzol, are lost.

Some advance was made by the consumption of coke and anthracite in the closed stove, and kitchen closed range, but this can only be economically accomplished by strict attention to the damper regulating the air inlet, or on the chimney flue, otherwise if the flue draught is keen, the fuel will burn away too rapidly, overheating will occur, and if there is a deep fire, with limited heated air supply, fuel will be wasted in the unconsumed gases entering the chimney.

For the elimination of the smoke nuisance a great number of inventions have been brought out, both for steam-raising furnaces and other purposes, including the domestic fire-grate, but very little success has been attained with the latter. The new fuel described in the chapter on "Low Temperature Carbonisation" has been manufactured and made purposely for consumption in the domestic open fire-grate, and only requires to be placed on the market at a reasonable price to ensure the abolition of smoke desired in large towns. This is a step in the right direction, making a fuel that will burn in the ordinary grate without emitting smoke, and also during its manufacture recovering the valuable by-products. In its consumption in the fire-grate, however, as compared with hard coke made by the gas companies, it will not be so economical; being softer, it will be more rapidly consumed.

Time Required for Combustion.

In the consumption of fuel, time is an important factor, and heat units given from a certain quantity of fuel require time for the purpose of development and absorption during the process of combustion. The heat from an explosive mixture may be as great as from the same weight of charcoal, which requires time for its consumption, but the economic use of an explosion is negligible, compared with the heat given by the slow combustion of the charcoal. The amount of heat generated in the perfect combustion of any fuel in the same allotropic condition is the same, whether combustion is rapid or slow; the meaning of the term perfect combustion as used above is that the absolute amount of oxygen be absorbed with which the carbon in the fuel is capable of combining to form carbonic acid gas, and the hydrogen compounds to form water.

Calorific intensity must be distinguished from the quantity of heat developed during combustion. Two bodies of the same weight may be consumed, but one of them may give out much more heat per second than the other, the heat of the former being very much more intense than that of the latter, and the intensity of heat developed in both will be in proportion to the time occupied during combustion.

"When a piece of well-carbonised dry charcoal is ignited and exposed freely to the air, it burns without sensible flame, and the product is carbonic acid gas. When, on the other hand, a piece of light, dry wood is ignited, it burns with much flame, and the products, if the combustion be perfect, are carbonic acid and water. Ordinary flame is gas or vapour of which the *surface* in contact with atmospheric air is burning with emission of light. The truth of this proposition may be easily demonstrated by experiment upon the flame of a candle or gas-jet, as is stated in every treatise on chemistry. There is no sensible intermixture of the gas and its supporter of combustion, for in that case there would be an explosion, attended only with the instantaneous production of flame. The piece of charcoal contains nothing from which inflammable gas can be produced in sensible quantity by the application of heat, and the solid carbon in combustion passes directly to the state of carbonic acid gas. Hence, there can be no flame. But, when a piece of wood is ignited, the case is different. The inner substance of the wood immediately below its burning surface is in precisely the same condition as wood which is heated in a closed vessel, and evolves various inflammable volatile matters, of which some are permanently gaseous and others condensable into liquids; hence, there must be flame. However numerous these products may be it should be remembered that, so long as they are ultimately converted into carbonic acid and water, the proposition, previously announced, respecting the quantity of heat developed is correct. When a piece of charcoal smoulders away in atmospheric air, or when it is burnt in oxygen gas, light is evolved. In the former case the light is only dull red, while in the latter case it is intensely brilliant, yet without sensible flame." *

Time, therefore, being an economical factor in the consumption of fuel, it is a question of how to get the maximum amount of heat from a given quantity of fuel in a given time; the harder the fuel, the longer time will be taken to consume it; this being the case, it is a matter of using the hardest kind of fuel if it can be procured at a relatively proportional cost compared with a softer kind of fuel. In the problem of consuming hard coke or anthracite in an open fire-grate, the attempts to accomplish this have not hitherto been attended

* Percy, "Metallurgy," Fuel, p. 157.

with much success, and the reason is obvious. The design of the open fire-grate is not fitted to supply the air for combustion, to convey it in a constant uniform amount to all parts of the fuel at the same time ; neither is it designed to allow the heat developed to be fully radiated and used.

An ordinary domestic grate, as already stated, is only open in the front to admit air, and supply the whole of the radiation from the fuel ; the two sides and back are solid bricks, or slabs of fireclay material. The fire-grate thus constructed, when filled with hard fuel, such as coke or anthracite, cannot consume it, on account of the limited supply of air at the proper temperature to maintain combustion throughout the whole of the fuel. It is a well-known fact that hard fuel such as mentioned above cannot be ignited alone ; some kind of softer fuel must be used, such as wood, to create enough local heat to raise the hard fuel to the state of incandescence ; when this has been accomplished, and the soft fuel has been consumed, the ingress of atmospheric air being confined to the front bars, with a very small amount at the bottom, the cold air striking the hard fuel (if in comparatively large pieces) chills it on the face, reduces the radiation of heat therefrom, and absorbs the heat from the fuel in its passage into the fire ; should the draught not be strong enough, the combustion of the interior fuel will go on too slowly to compensate the heat extracted from the fuel by the cold ingress of air, and the fire will gradually lose heat and become extinguished. The back and sides of the grate supply no air for combustion, but absorb heat, and therefore cannot maintain combusion ; if, however, it were possible to have a free supply of air all round the fire-grate, including all sides and the back, hard fuel of any kind could easily be consumed.

For the purpose of consuming hard, smokeless fuel such as anthracite, foundry, furnace, or gas works coke, the author has designed a fire-grate wherein these fuels can be economically burned, with means of utilising the maximum of the heat developed. The following is a description of this new domestic fire-grate :—

This fire-grate, for domestic use, is entirely different from those generally in use at present ; it is constructed without closed back or sides, and is preferably not fixed or built into the brickwork wall of the chamber. The grate is constructed of a triangular, square, round or other shape on horizontal plan, and is preferably (but not necessarily) of a tapered shape vertically. The bars are generally made flat and inclined inwards, and are placed on all sides, and in some cases are made moveable, by means of a lever, in order to adjust the distance of the opening between each bar, for the regulation of the air. The tapering form provides means to enable the ashes to be directed to the centre downwards, so that no ashes fall out of the grate, while the full radiation of the fuel is maintained.

In a model, for instance, of a triangular form, one of the three sides is placed in front, from which radiation of heat is direct, but on the two other sides the radiation of heat into the apartment is accomplished by reflection. The point or junction of these two receding sides is at the back, and the recess of the wall occupied by the grate is formed in a similar manner, but at a much more obtuse angle. The angle of the two walls of the recess is made to face the walls of the fire-grate, but the angle at which they are set is greater. (The angle of reflection is always equal to the angle of incidence.) This being so, the reflecting sides of the recess are placed so that the heat is directed into the apartment. The sides of this recess may be made of any kind of reflecting substance, such as polished metal, porcelain, or other substance. There being

no smoke, and the products of combustion being gaseous, and in order to conserve the heat, a much smaller chimney opening is used than with the ordinary grate; in fact, the opening is just sufficient to take away the products of the combustion of the fuel, and allow for a certain amount of ventilation of the apartment, which can be controlled by a damper, the grate being placed under the opening to the chimney.

Under these circumstances there is no waste of heat, all the possible heat that is radiated from the fuel is directed into the apartment, combined with the consumption of hard fuel that otherwise cannot be used in the domestic grate, while the design allows scope for a beautiful and artistic effect.

The use of smokeless fuel means economy, not only in the recovery of the other valuable constituents of the fuel during its manufacture, but in the domestic sphere as well; most of the expenditure upon a house in cleaning, decoration, painting, furniture coverings, etc., is due to coal smoke; when this is eliminated, the interior as well as the exterior will last longer, and provide an atmosphere purer and healthier than at present.

The heating of domestic apartments by means of gas is now a *fait accompli*. Early attempts were an absolute failure, because the proper method of combustion and the best design of apparatus were not then understood, and in many instances this want of economic and practical knowledge in the design of the apparatus is still apparent. In the early days of gas heating, gas was burned like coal, in an open fire-grate, with the result that a large amount of gas was consumed, without the desired result of heating the apartment, and some prejudice arose in the public mind against gas heating through the erroneous idea that the gas fire produced an unhealthy atmosphere in the apartment, and remarks were made "that a coal fire did not give out the same bad atmosphere as a gas fire." The author has had to point out to those expressing such remarks that in reality the reverse is the case. The gas consumed in a properly constructed gas fire is in reality purer than the gas burned on the surface of a coal fire, because the gas manufactured from coal at the gas works is purified, deleterious matters such as sulphur being extracted, which substances are never destroyed during combustion, their form only being changed; so that with a coal-fed fire these noxious gases often find their way into the apartment and into the atmosphere outside.

There is, however, much to be done towards the perfection of the domestic gas fire, towards getting the full amount of heat from the gas consumed, together with the thorough heating of the apartment, with perfect ventilation. This latter is one essential advantage that the open fire-grate has over all other systems of heating, the air of the apartment is continually being changed by the draught of the chimney.

This has not been fully appreciated or observed by gas engineers in the design of their gas fires. At first, and even yet, the opening into the chimney is too large, which results in a drawing away of most of the heat into the chimney, while the construction of the fire itself does not permit of the abstraction of the heat into the medium, to radiate the maximum amount available by the amount of gas consumed; heat is, therefore, lost into the chimney.

Another loss of heat units resulted from the comparatively bad combustion of the gas. To consume gas properly, and to make use of the maximum amount of heat developed in a gas fire, there must be an approach to perfect combustion with atmospheric air, producing carbonic acid gas and water; but under the conditions obtaining in the methods adopted at present, these ideal results are seldom realised.

As stated above, in connection with the consumption of hard fuel, the chilling effect due to the entrance to a gas fire of the secondary cold atmospheric air extracts a certain amount of the heat from the face of the medium that would otherwise be radiated into the apartment. This can be easily proved by the fact that at that part of the fire (generally in the front) where the secondary air for combustion enters, the face of the incandescent medium is chilled, and is never of the same heat as obtains in the interior of the incandescent mass. It is only where a fire is so constructed as to expose for radiation the maximum amount of this highly heated interior, with the minimum of the chilled exterior, that anything like an efficient result can be obtained from the gas consumed.

Unlike the gas furnace, with recuperator or regenerator, the waste gases of combustion from a gas fire enter the chimney flue at a pretty good temperature; the heat units of the waste gases are, therefore, lost.

Another difficulty in connection with the proper combustion of gas in a gas fire is the adjustment of the proper proportion of air admitted to the primary air and gas mixer; an adjustable valve is always necessary on the air intake for this purpose.

A very great improvement can be made also in the recuperative method designed by the author by admitting the secondary air as heated air, by which the chilling effect stated above is to a large extent obviated, and a higher temperature can be maintained in the fire, although this necessitates a more complicated construction, and consequently more expensive apparatus, as regards first cost, but is ultimately more economical in general use.

The author has for the last 30 years used only gas for heating and cooking in his home, with a considerable saving in cost, and in domestic service, decorations, furniture, curtains, and other items generally damaged and destroyed by coal smoke and dust. The library is heated by a gas fire made by the author as long ago as 1898, fitted and supplied with a $\frac{1}{4}$-inch gas pipe, maintaining an incandescent, radiating surface of 15 inches by 16 inches; the exit to the chimney is only about $1\frac{1}{2}$ inches by 15 inches; although the room contains over 2,700 cubic feet, it is perfectly warmed and ventilated. The author is of opinion that the fuel of the future for most purposes will be a gaseous fuel; it is easy to distribute, and easily lighted; by the turn of a tap it can be used or extinguished at once. It creates no dirt or dust, and requires only a tube instead of a chimney to carry away the products of combustion, and for cooking it is an ideal fuel; the flame or heat can be regulated to any requirement, and it is a great time-saver. Since the introduction of the incandescent gas mantle for lighting, gas companies have been enabled to supply gas of a quality that will produce greater heat for the purpose of cooking and warming than was possible previously, and comparatively more cheaply; and when all domestic expenditure is carefully calculated and compared with the system of heating and cooking by coal, it will be found, as the author has proved in his experience, that there is a very considerable saving when using gas.

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